EXPERIMENTAL INVESTIGATION OF THE MINIMUM QUANTITY LUBRICATION IN END-MILLING OF AA6061T6 BY COATED CARBIDE TOOLS

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JUDUL: **EXPERIMENTAL INVESTIGATION OF THE MINIMUM QUANTITY LUBRICATION IN END-MILLING OF AA6061T6 BY COATED CARBIDE TOOLS**

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Dedicated, in thankful appreciation to my beloved family and friends.

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ABSTRACT

This report presents an experimental investigation on the effects of output parameters which are surface roughness, tool wear and material removal rate during machining aluminum alloy 6061-T6 using minimum quantity lubricant (MQL) technique. The minimum quantity of lubrication technique is becoming increasingly more popular due to the safety of environment. The cutting speed, depth of cut, feed rate and MQL flow rate are selected input parameters in this study. This experiment was conducted based on central composite design method. To develop a model of process optimization based on the response surface method. MQL parameters include nozzle direction in relation to feed direction, nozzle elevation angle, distance from the nozzle tip to the cutting zone, lubricant flow rate and air pressure. To achieve a maximum output parameters based on the optimized process parameters for coated carbide cutting tools (CTP 2235). The surface roughness was increased with decrease of cutting speed. The optimum cutting condition for MQL and flooded are obtained the feed rate, depth of cut, cutting speed and MQL flow rate are 379 mm/tooth, 2 mm, 5548.258 rpm and 0.333 ml/min respectively for MQL. The optimum cutting condition for flooded are obtained the feed rate, depth of cut, cutting speed and MQL flow rate are 379 mm/tooth, 2 mm and 5563.299 rpm respectively for flooded. It is seen that a majority of coated carbide inserts have a long tool wear when exposed to high cutting speed, and feed rate leading to breakage of the inserts.

ABSTRAK

Laporan ini membentangkan siasatan ujikaji mengenai kesan parameter pengeluar iaitu kekasaran permukaan, pemakaian alat dan kadar penyingkiran bahan semasa pemesinan aloi aluminium 6061-T6 menggunakan minimum kuantiti pelincir (MQL) teknik. Teknik minimum kuantiti pelinciran menjadi semakin popular kerana keselamatan alam sekitar. Kelajuan pemotongan, kedalaman pemotongan, 'feed rate' dan kadar aliran MQL dipilih menjadi parameter kemasukan dalam kajian ini. Eksperimen ini telah dijalankan berdasarkan reka bentuk komposit pusat kaedah. Untuk membentuk model pengoptimuman berdasarkan kaedah gerak balas permukaan. Parameter MQL termasuk arah muncung berhubung dengan makanan haiwan arah, sudut ketinggian jarak muncung dari hujung muncung ke zon pemotongan, kadar aliran pelincir dan tekanan udara. Untuk mencapai parameter pengeluar maksimum berdasarkan proses parameter dioptimumkan untuk bersalut alat pemotong karbida (CTP 2235). Kekasaran permukaan telah meningkat dengan penurunan kelajuan pemotongan. Keadaan pemotongan optimum untuk MQL dan 'flooded' diperolehi 'feed rate', kedalaman potongan, kelajuan pemotongan dan kadar aliran MQL adalah 379 mm/gigi, 2 mm, 5548,258 rpm dan 0.333 ml/min masing-masing untuk MQL. Keadaan pemotongan optimum untuk 'flooded' diperolehi 'feed rate', kedalaman potongan, kelajuan pemotongan dan kadar aliran MQL adalah 379 mm/gigi, 2 mm dan 5563,299 rpm masing-masing untuk 'flooded'. Ia dilihat bahawa majoriti 'insert' bersalut karbida mempunyai pemakaian alat yang lama apabila terdedah kepada kelajuan pemotongan yang tinggi, dan 'feed rate' yang membawa kepada kerosakan kepada 'inserts'.

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LIST OF SYMBOLS

RPM	Revolution per minute
v_c	cutting speed
f_r	feed rate in mm/rev
f_t	Feed rate in mm/tooth
n	Number of the teeth of cutter
R_a	Average surface roughness
L	Sampling length
Y	Ordinate of the profile curve
V	Cutting speed
T	Tool life (minutes)
C	Taylor's constant for the unaccounted variables
N	RPM of Cutter
W	Width of cut (may be full cutter or partial cutter)
t	Depth of cut
L	Length of pass or cut
f_m	Table (machine) Feed
D	Cutter Diameter in mm

LIST OF ABBREVIATIONS

MQL	Minimum quantity lubrication
RSM	Response surface method
CNC	Computer numerical control
TiC	Titanium carbide
TiCN	Titanium carbon nitride
TiN	Titanium nitride
PVD	Physical vapour deposition
CVD	Chemical vapor deposition
NDM	Near dry machining
DOE	Design of Experiment
RPM	Revolution per minute
CBN	Cubic boron nitride
GF	Green factor
ISO	International standard organization
HSS	High Speed Steel
CLA	Center Line Average
AA	Arithmetic Average
Ra	Average roughness
MRR	Material Removal Rate
C_S	Cutting speed
SR	Surface roughness

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Manufacturing usually occurs in large scale that involves mass of production. Beside the manufacturers in the competitive marketplace because of the manufacturing environment, low costs, goals of high rates of production, and high quality. The minimization of cutting fluid also leads to economic benefits by way of saving lubricant costs and workpiece/tool/machine cleaning cycle time (Dhar et al., 2006). In order to improve the traditional manufacturing, many technologies are developed and it causes many machines have been created as well as the tools themselves. There are many types of machine and tools that are used to process the material in manufacturing process. Some of them may involve high cost to operate the process such as cost of machine, cost of maintainence, energy consumption, labor and so on. Therefore, in mass production, it is important to consider the economic aspect in order to make the industry profitable and growth. Many traditional techniques and hybrid methodologies have been developed to make the manufacturing process more effective such as directly assess the machining performance (Jawahir et al., 2003).

Machining process require specific cutting tools to be used in order to obtain optimum machining performance. We can use high quality of material to create better tool for example by using TiN-coated carbide cutting tool as it can stand at high temperature, high cutting-speed and it was prove that can improve the tool life. The coated tools are used more than 40 % in industry and perform more than 80 % to all machining (Cselle and Barimani, 1995). However, the performance of that cutting tool is depending on many variable of cutting conditions.

This project focused on the technique to apply MQL performed in machining AA6061-T6 using coated carbide tool and CNC end milling machine. The mechanical properties for AA6061-T6 depend greatly on the temper, heat treatment, of the material. The aluminum offers advantages over other materials because of its relatively low density, high recyclability, design flexibility in mass production and economic benefit (Chu and Xu, 2004). Besides that, the aluminum is getting more popular due to increasing concern in fuel economy and stringent government emission regulations, lightweight materials Aluminum are also being extensively adopted by design engineers for structural components. Surface finish is essential factor in evaluating the quality of products and average surface roughness (R_a) most is common index used to determine the surface finish. The response surface method (RSM) as a statistical method that been used to optimize the surface responses. The RSM quantifies the relationship between response surfaces and input parameters. Fuh and Hwang (1997) constructed a model that can predict the milling force in end milling operations by using RSM method. They measured the speed of spindle rotation, feed per tooth and axial and radial depth of cut as the three major factors that affect in milling operation. The comparison between the experimental data and the values predicted by this prediction model showed the model's accuracy to be as high as 95 %. In this experiment focuses on best usage of machining AA6061-T6 and coated carbide in respect to the cutting force, tool life and surface roughness using the RSM approaches in the CNC milling machine.

1.2 PROBLEM STATEMENT

Performances of milling machine almost depend highly on how fast the machine can cut the work piece. Ulutan and Ozel (2011) mentioned that the accuracy of workpiece dimension, tool wear, surface finish, and tool life on the MRR and cutting tool have increased for enhancing the product performance in relation to the impact of the environment. High productivity needs high rate of metal removal, so it can reduce manufacturing cost and operation time. The large amount of the cutting fluid used in machining is damaging and environmentally harmful become it may contain damaging chemical elements which is dangerous to the skin and lung of the operators plus it can couse air pollution (Sreejith, 2008). The minimal quantity lubrication will be used in our experimental will be compare with another cutting fluid. MQL in an end-milling process is very much effective regarding (Lopez de Lacalle et al., 2004) and they mentioned that MQL can reach the tool face more easily in milling operations compared with other cutting operations. AA6061-T6 is more suitable choice due to its cost-efficient element (MacMaster et al., 2000) and economical aspect has always been important when it comes to mass production while there is more material such as aluminum alloy AA 6069 (Chu and Xu, 2004). Ghani et al. (2004a) investigated that the coating typically reduced the coefficient of friction between the cutting tools and reduce the tool wear. Eventually, sudden failure of cutting tools lead to loss of productivity, rejection of parts and consequential economic losses. The coated carbide tool is to be considered in this study to evaluate the performance of a machining process depends on tool wear or tool life.

1.3 OBJECTIVE OF THE PROJECT

The objectives of this project are as follows:

i. To experimentally investigate the machining characteristics of aluminum alloy in end mill processes for flooded and MQL techniques.
ii. To investigate surface quality finish of coated carbide cutting tool by using MQL method.
iii. To study the tool wear and the material removal rate regarding the MQL technique.

1.4 PROJECT SCOPE

i. Using CNC milling machine to operate the end milling on AA6061T6 by coated carbide using MQL.
ii. Determine optimum performance of coated carbide cutting tools in milling operation by vary machining parameter which is cutting speed, feed and depth of cut.
iii. Design of experiments and Optimization model develop are prepared using MiniTab software.
iv. Mathematical model used response surface method.

1.5 ORGANIZATION OF REPORT

There are five chapters including introduction chapter in this study. Chapter 2 presents the literature review of previous studies includes the end milling, process parameters, response parameters, prediction modelling. Meanwhile, Chapter 3 discusses the design of experiment, preparation of experimentation, mathematical modelling techniques and statistical methods. In Chapter 4, the important findings are presented in this chapter. Chapter 5 concludes the outcomes of this study and recommendations for future research.

CHAPTER 2

LITERITURE REVIEW

2.1 INTRODUCTION

This chapter provides the review from previous research efforts related to milling process, CNC milling machine, cutting parameters in milling machine, and cutting tools. This chapter also involves a review some research studies like the statistical method which is related to the mathematical modeling the present study. Substantial literature has been studied on machinability of aluminum alloys which is covers on surface roughness, tool life, tool wear cutting force and chip formation. This review has been well elaborated to cover different dimensions about the current content of the literature, the scope and the direction of current research. This study has been made in order to help identifying proper parameters involved for this experiment. The review is fairly detailed so that the present research effort can be properly tailored to add to the current body of the literature as well as to justify the scope and direction of present.

2.2 MILLING MACHINE

A milling machine is a machine tool used to machine solid materials. Milling machines exist in two basic forms: horizontal and vertical, which terms refer to the orientation of the cutting tool spindle. Milling is the most common form of machining process used in the production of moulds, due to the high tolerances and surface finishes by cutting away the unwanted material. A serious attention is given to accuracy and surface roughness of the product by the industry these days (Nagallapati et al., 2011). workpiece and cutter movement are precisely controlled to less than 0.025 mm, usually by means of precision ground slides and lead screws or analogous technology. Milling machines may be manually operated, mechanically automated, or digitally automated via computer numerical control (CNC). Wang et al. (2004) also stated that the end-milling operation is an oblique cutting process. There have been a lot of important factors to predict machining performances of any machining operation, such as surface roughness and dimensional accuracy.

The study conducted by Rahman et al. (2002) revealed that for a given machine tool and the workpiece setup, the cutting parameters such as speed, feed, depth of cut and tool nose radius have significant influences on the surface roughness. Milling can be defined as machining process in which metal is removed by a rotating multiple-tooth cutter with each tooth removes small amount of metal in each revolution of the spindle. Because both workpiece and cutter can be moved in more than one direction at the same time, surfaces having almost any orientation can be machined.

2.2.1 Type of Milling Machine

The plain vertical milling machines (Figure 2.1) is the modern vertical milling machines are designed so the entire head can also swivel to permit working on angular surfaces. In the vertical mill the spindle axis is vertically oriented. Milling cutters are held in the spindle and rotate on its axis. The spindle can generally be extended or the table can be raised or lowered, giving the same effect allowing plunge cuts and drilling. There are two subcategories of vertical mills: the bed mill and the turret mill. The plain horizontal milling machines (Figure 2.2) column contains the drive motor and an adjustable overhead arm containing one or more arbor supports projects forward from the top of the column. A horizontal mill has the same sort of *x–y* table, but the cutters are mounted on a horizontal arbor (see Arbor milling) across the table. Many horizontal mills also feature a built-in rotary table that allows milling at various angles. The arm and arbor support are used to stabilize long arbors. Supports can be moved along the overhead arm to support the arbor where support is desired depending on the position of the milling cutter or cutters.

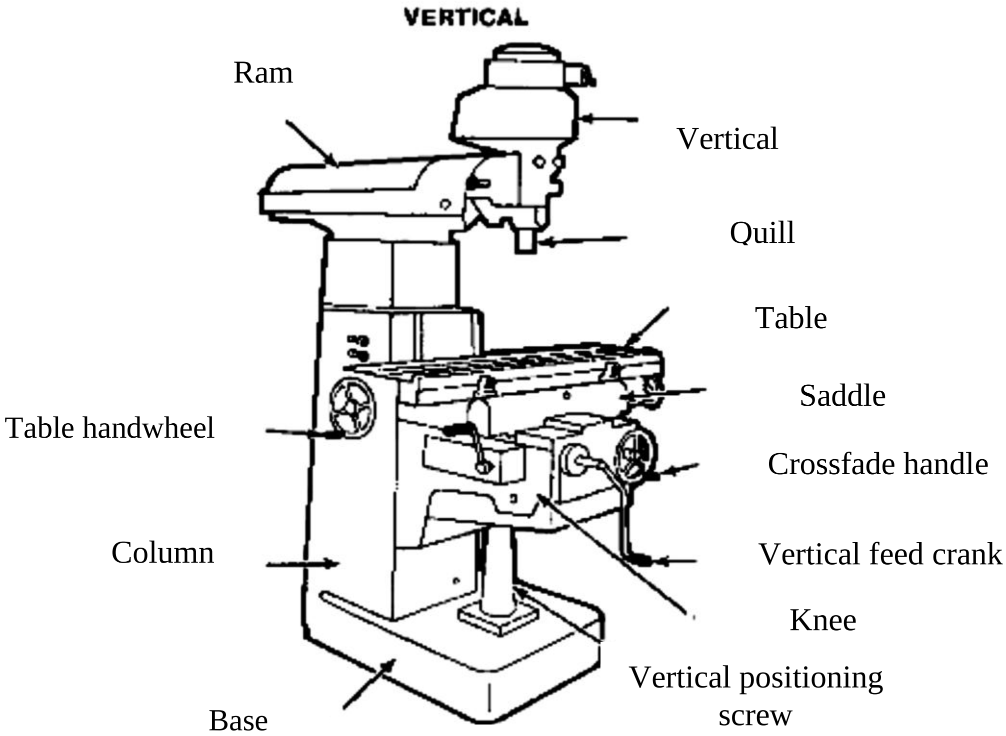


Figure 2.1: Vertical milling machine

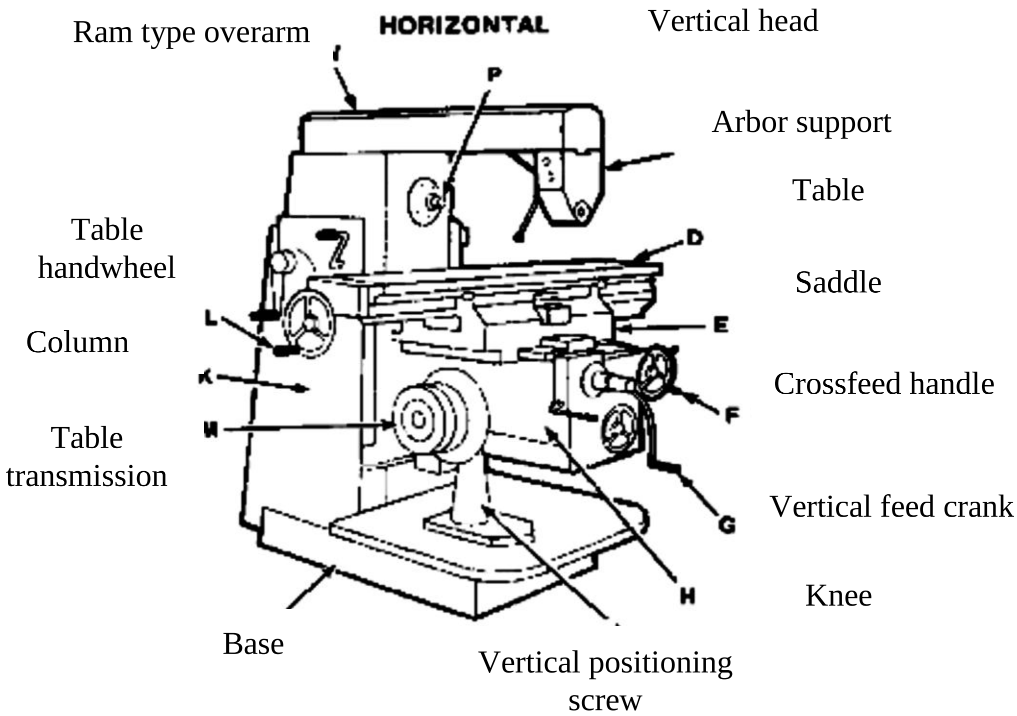


Figure 2.2: Horizontal milling machine

2.2.2 End Milling Machine

The milling process can provide surface finishes and high tolerances and surface finishes that is why it is deemed as the best way for adding precision features to a part whose basic shape has been formed previously (Dotcheva and Millward, 2005). The depth of the feature may be machined in a single pass or may be reached by machining at a smaller axial depth of cut and making multiple passes. For a rough operation, the recommended cutting speed and feed are selected for a peripheral or slot cut. A finish operation will lower the cutting feed according to the finish requirements. Figure 2.3 shows an end milling process and the type of end mill used most abundantly is 2- flute and 4-flute. According Dang et al. (2010), a lot of aerospace components such as dies and moulds are commonly done by the machining processes of the flat end milling.

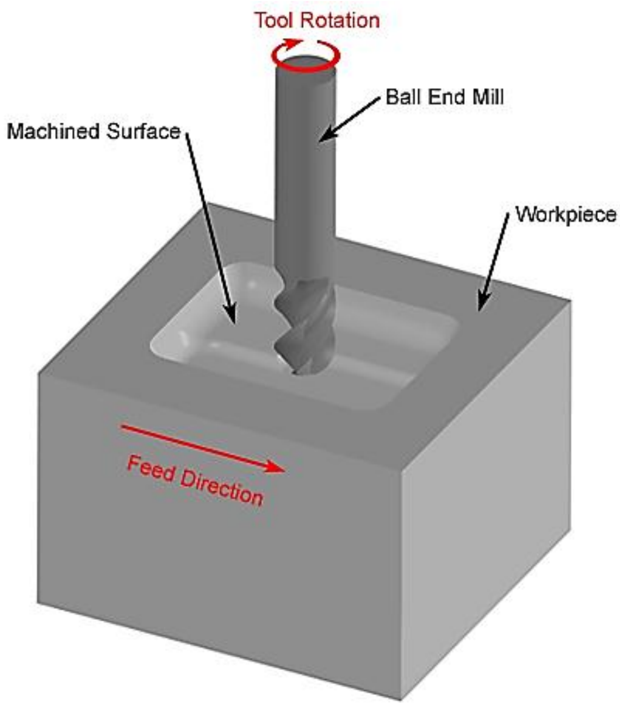
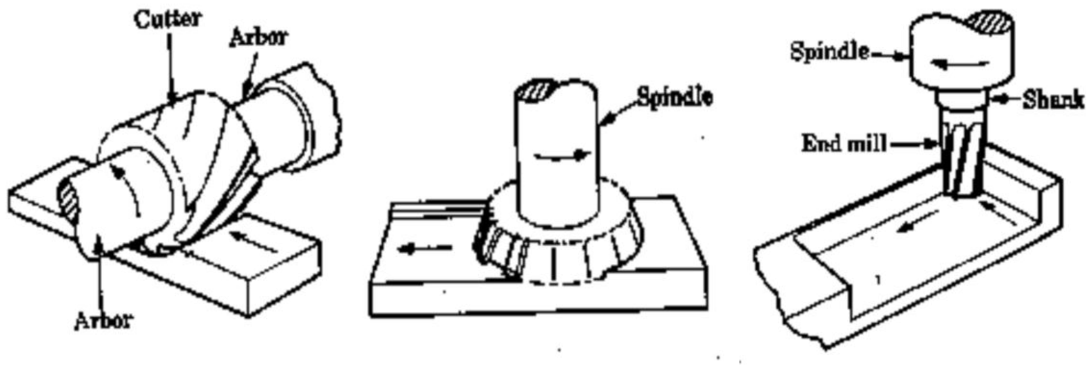


Figure 2.3: End milling process

2.2.3 Operation of Milling Machine

Figure 2.4(a) shows the slab milling. The axis of cutter rotation is generally in a plane parallel to the workpiece surface to be machined. Peripheral milling processes are widely used for the rough or finish cutting of profiled components. Figure 2.4(b) presents the face milling and the cutter of this milling mounted on a spindle having an axis of rotation perpendicular to the workpiece surface. The milled surface results from the action of cutting edges located on the periphery and face of the cutter. Figure 2.4(c) is end milling which is generally rotates on an axis vertical to the workpiece. It can be tilted to machine tapered surfaces. Cutting teeth are located on both the end face of the cutter and the periphery of the cutter body.



(a) (b) (c)

Figure 2.4: Different operation of miling machine.

2.3 COATED CARBIDE TOOLS

The selection of cutting tools in order to perfume in machining operation is very important. According to Cselle and Barimani (1995) stated that the sold value more than 40 % of all cutting tools are coated in modern industry today. The market share of coated tools is growing continuously, but the different tools and cutting operations need different coatings.

Coating have unique properties, such as higher adhesion, lower friction, higher resistance to wear and cracking, higher hot hardness and impact resistance. Che-Haron et al. (2007) stated during the process of machining with coated and uncoated carbide tools failure results because of the stark flank wear and notching at the tool nose and the depth of cut line. This improvement had a major impact on the economics of machining operation in conjunction with continued improvement in the design and construction of modern machine tools and their computer controls. As a result, coated tools nowadays are used more than 40 % in industry and perform more than 80 % to all machining use (Cselle and Barimani, 1995). Sahin and Motorcu (2005) explained the coated carbides mare basically a cemented carbide insert material coated with one or more thin layers of wear resistant material such as titanium carbide (TiC), Titanium nitride (TiN) and aluminum oxide (Al_2O_3). The cutting tools coated carbide inserts have two techniques, physical vapor deposition (PVD) and chemical vapor deposition (CVD). According to Dudzinski et al. (2004), CTW 4615 is a coated carbide grade with TiAlN coating PVD with grade designation P35 M50. Titanium-aluminium nitride (TiA1N) is used in the cutting of material like difficult -to- machine material.

2.4 MINIMUM QUANTITY LUBRICATION

Minimum quantity lubrication is constructed on the principle that a drop of liquid is split by an air flow, distributed in streaks and transported in the direction of flow of air. The consumptions oil in industrial applications is in the range of approximately 10-100 ml per hour (Kamata and Obikawa 2007). In machining, conventional cutting fluid application fails to penetrate the chip-tool interface and thus cannot remove heat effectively. According Klocke and Eisenblatter (1997) stated that the overall performance of cutting operations MQL is very attractive as it consists of cutting fluid volume reduction, by use of small amounts of fluid. The present work experimentally investigates the role of MQL on surface roughness, tool flank wear in end milling at different speed combinations by high speed super cobalt tool.

The minimum quantity lubrication represents the use of cutting fluid in smaller quantity which is around ten-thousandth of the amount of cutting fluid used in flood-cooled machining (Machado and Wallbank, 1997) and (Rahman et al., 2001). MQL contains of a mixture of pressurized air and oil micro-droplets applied directly into the interface between the tool and chips. However, the question of how the lubricants can decrease the friction under very high temperature and loads is still not answered especially for long engagements times. The MQL machining is nearly equal or often better than the traditional wet machining in tool life and surface finish when cutting steels and aluminum alloys (Kamata and Obikawa, 2007).

2.5 ALUMINUM ALLOY

Aluminum alloys are alloys in which aluminum is the predominant metal. Characteristic alloying elements are copper, zinc, manganese, silicon, and magnesium. Cselle (1995) mentioned that the majority of aluminum alloys can be machined at high-speed practically without sacrificing tool life. In that case the dynamics of machine tool and fixture set the upper limit for surface speed in cutting. About 85 % of aluminum is used for wrought products, for example rolled plate, foils and extrusions. AA6061-T6 is high strength Al–Mg–Si alloys that can increase the ductility and the toughness. The aluminum alloys are widely used in engineering structures and mechanisms where light weight or corrosion resistance is required (Robert and Richard, 1997). Many organizations publish more specific standards for the manufacture of aluminum alloy, including the Society of Automotive Engineers standards organization, specifically its aerospace standards subgroups (Sreejith, 2008).

2.6 PROCESS PARAMETERS

The parameter dependS on the machining properties such as how maximum spindle speed that the machining can conduct. According Kincl et al. (2005), the procedure of choosing the optimum level of cutting tools, machines and cutting parameters and condition is very long and costly. These experiments have the input and output conduct by the DOE. The input are depth of cut, radial depth of cut, feed rate, cutting speed and the flow rate of the MQL. The outputs for this experiment are surface roughness tool wear and material removal rate.

2.6.1 Cutting Speed

Cutting speed is the speed at the outside edge of the milling cutter as it is rotating. The hardness of the cutting tool has a great deal to with the recommended cutting speed. Based on the observation by Ravi and Kumar (2011), the cutting speed increased, the cutting temperature increases under all the machining conditions, which may be attributed to an increase in the cutting energy dissipation rate. The cutting speed must be set to the machine to ensure the cutting operation is correct and to avoid the cutting tool and workpiece damage during the cutting operation. To set the cutting speed we need to calculate the revolution per minute (RPM). The RPM calculation depends on the cutting speed and the size of the cutter. The cutting speeds can be expressed as Equation (2.1):

$$RPM = \frac{\text{Cutting speed} \times 4}{\text{Diameter of cutter}} \tag{2.1}$$

The spindle speed suggested by Dhar et al. (2006) for the steel according to milling machine is 110 m/min and it is a good finish surface roughness. The value of the spindle speed is fix and the optimum value for these is 110 m/min. Amin et al. (2007) carried out an experimental study and suggested that the spindle speed is 120 m/min to 250 m/min and it observed to cutting performance tools wear related to the uncoated carbide in term of tool life. The final optimum value of this parameter is 120 m/min related to the surface roughness and the tool wear according to the experiment. Ezugwu et al. (2005) valuated the cutting performance of different CBN tool grades in finish turning Ti–6Al–4V (IMI 318) alloy at high cutting conditions, up to 250 m/min, with various coolant supplies. They investigated the tool wear, failure modes, cutting and feed forces and surface roughness of machined and used to access the performance of the cutting tools. The value of cutting speed given by Liao et al. (2007) is 150 m/min for the minimum and 250 m/min for the maximum value. The general expectation shows when the increasing of the cutting speed the cutting force will decrease. The optimum value is the range of 200 m/min to 250 m/min for the best result of the surface finish.

The research carried out by Attanasio et al. (2006) to determine the technique advantages to the tool wear reduction using the rake and flank tool decided to use the fix value for the spindle speed which is 300 m/min. The optimum value is 300 m/min to guarantee acquire the best condition for tool. Arumugam et al. (2006) investigated that the cutting speed 480 to 690 m/min was selected in dry machining of aluminum-silicon alloy experiment. Based on the experiment the optimum value is 690 m/min that make the surface finish, feed and depth of cut in optimizing the mass concentration.

Ghani et al. (2004b) make an analysis according to the experiment performance of P10 TiN coated carbide at high cutting steel by end milling with cutting speed 224 m/min to 355 m/min. In research study carried out by Yan et al. (2012), the influence of MQL on surface roughness in milling and the cutting speed is 94.2 m/min to 219.8 m/min and the optimum value is obtained of 219.8 m/min. In another experiment by using the liquid nitrogen in end milling, Ravi and Kumar (2011) used the cutting speed range of 75 m/min to 250 m/min. 75 m/min is the optimum value that decided in which to provide in low cutting temperature, tool wear, surface roughness and the cutting force.

2.6.2 Feed Rate

Feet rate is refer to how fast the cutting tool moves through the workpiece. This parameter unit is usually mm/rev. Liao et al. (2007) suggested that the value of the feed rate is 0.10 mm/rev to 0.2 mm/rev according to the experiment of MQL in high milling by coated carbide. The optimum feed rate of the experiment 0.15 mm/rev to achieve the good surface finish. The MQL technique give advantages to tool wear (Attanasio et al., 2006). The range of the feed rate is decided between 0.20 mm/rev and 0.26 mm/rev. In the other hand, Arumugam et al. (2006) use the range feed rate between 0.2 mm/rev and 0.4 mm/rev in their investigated which is dry machining of aluminum–silicon alloy coated cutting tools insert. The result showed the work piece average surface roughness, the higher feed rate and depth of cut. Ghani et al. (2004b) investigated the performance of P10 TiN coated carbide in milling recommended the range of the feed rate is between 0.1 mm/tooth and 0.25 mm/tooth. The feed rate value increase in higher cutting force and requires more power consumption to remove the material and accordingly more heat produced at the tool edge.

A constant feed rate used in the experiment by Yuan et al. (2011) which is 0.075 mm/rev to produce better result with the different coolant strategies. The experiment modeling machining parameter in CNC end milling conducted by Nagallapati et al. (2011) decided the range of feed range in the experiment between 0.1 mm/tooth to 0.2 mm/tooth. The increase of feed rate will increase the heat generation, therefore the surface roughness also increase. Ghani et al. (2004b) investigated the wear mechanism of TiN coated and uncoated carbide at high cutting speed mentioned the feed rate between 0.1 mm/tooth ant 0.25 mm/tooth. The optimum value is 0.1 mm/tooth.

2.6.3 Axial Depth of Cut

The depth of cut means that the depth of the workpiece when the cutting operation run along it axis as shown in Figure 2.5. According to Ghani et al. (2004a) the use of high depth of cut combined with high cutting speed and feed rate could cause more severe damage on the cutting edge than at low cutting speed and feed rate combination although the tool failure mode was similar. Itoigawa et al. (2006) had chosen the range of the axial depth of cut between 3 mm to 10 mm. The feasibility study of MQL in milling with high speed coated carbide tool used the constant axial depth of cut is 0.6 mm (Liao et al., 2007). MQL effect on the tool wear by Attanasio et al (2006) decided used the constant value of axial depth of cut 1 mm to guarantee the best working conditions in the experiment. The range of axial depth of cut is between 0.5 mm and 1 mm. The authors concluded that the highest green factor (GF) influence from combination of the high feed, high speed and high depth of cut. The axial depth of cut suggest in range between 0.5 mm to 1.5 mm. The author concluded that when the axial depth of cut increase the surface roughness will increase.

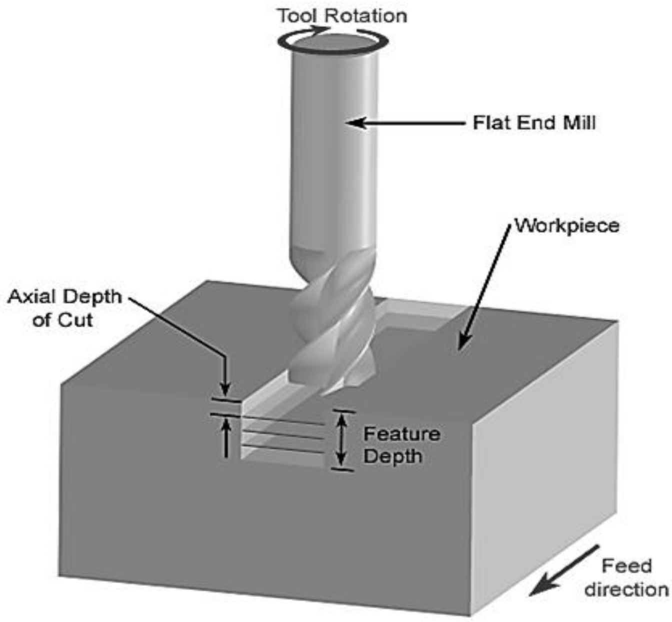


Figure 2.5: End milling (Milling machine)

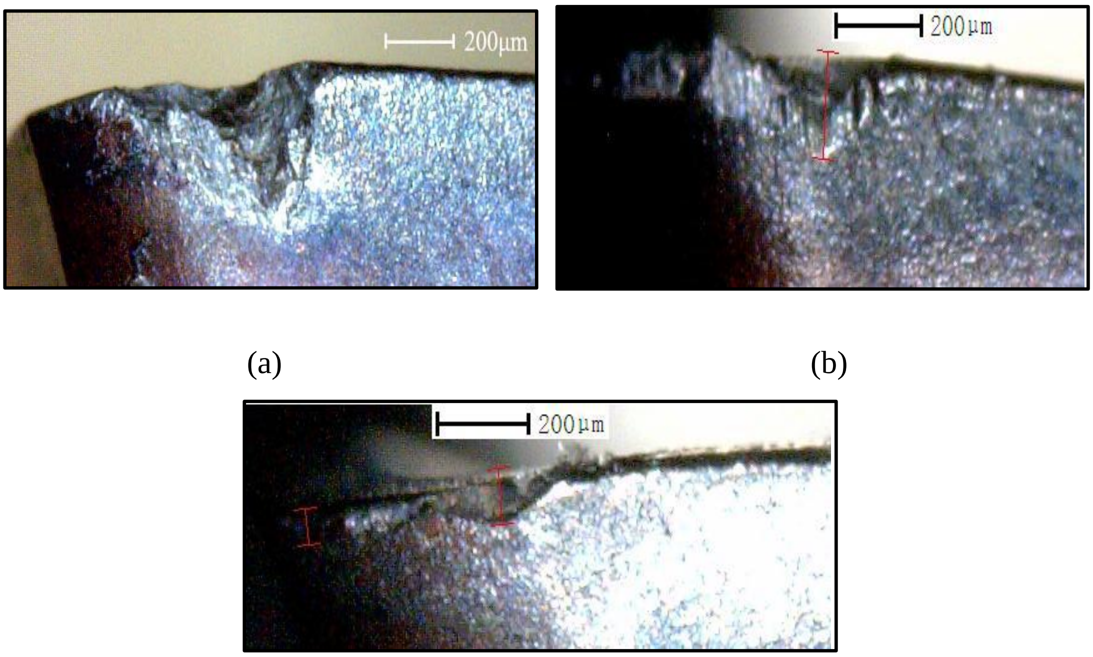
2.7 RESPONSE PARAMETERS

The output parameters also call response parameters are tool wear, surface roughness and material removal rate.

2.7.1 Tool Wear

Tool wear produced when the certain tool use in high impact jobs such as cutting or drilling. The tool wear have many different type and the wear influence type of tool use, type of operation machine done with tool. Flank tool wear is the common type of tool wear. Dhar et al. (2006) investigated the effect of MQL on tool wear and surface roughness and they conclude that the MQL provided reduce the tool wear, increase the tool life and produce good surface finish compare dry and wet machining. Lugscheider et al. (1997) used the same technique, MQL in processing the aluminum and gray cast iron with coated carbide and concluded that the MQL technique caused the reduction of tool wear compare another technique. Kang et al. (2008) applied the different technique in high speed by coated carbide tools in their experiment to discuss the effect for tool wear. The experiment used CCD camera to get the value of tool wears after use it. The cutting length increase and the tool wear will increase proportionally. Ghani et al. (2004a) found that the tool life drastically decrease when the cutting speed increase because of the high cutting speed high temperature and produce the tool wear accelerated.

The tool wear influence by the feed rate which is the increasing of feed rate the cutting force increases and supports the tool wear plus shortens the tool life. Nagallapati et al. (2011) in their experiment modeling of machining parameter in CNC determined that the tool wear resulted in higher surface roughness with the increasing of heat generation by increase the feed rate and axial depth of cut. Figure 2.6 presents the comparison of the tool wear for different cutting processes (Yan et al., 2012) and the MQL technique make the shorten tool wear. The three techniques operated in the same time which is in 32.16 min. The authors concluded that the MQL technique has increased the tool life by 2.03 times as compared to dry cutting and 1.72 times compared to conventional flood cutting fluid supply cutting.



(a) (b)

(c)

Figure 2.6: The comparison of the tool wear for different cutting processes (a) Dry cutting after 32.16 min, (b) Wet cutting after 32.16 min, (c) MQL cutting after 32.16 min

2.7.2 Surface Roughness

The surface roughness of a machined product could affect several of the product's functional attributes, such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating, and resisting fatigue (Lou and Chen, 1997). Surface roughness is the most important variable in surface finish. Surface roughness is a measure of the level of unevenness of the part's surface. Ghani et al. (2004a) noted that the low value of surface roughness and cutting force were acquired when the feed rate and depth of cut keep in low value. The surface roughness's produced in milling operation depend on feed rate. Da Silva et al. (2011) used the Surftest Mitutoyo portable stylus type instrument with sampling length of 0.8 mm to record the surface. The author recorded the average of the surface roughness value is between 0.15 and 1.1 µm. If a higher surface roughness is required it is essential that before the process starts the setting of cutting parameters is done properly (Lou et al., 1999). A profile meter has a diamond stylus that travels along a straight line over the surface.

The distance that the stylus travels is called cutoff, which generally range from 0.08 to 25 mm. a cutoff of 0.8 mm is typical for most engineering applications. The rule of thumb is that the cutoff must be large enough to include 10 to 15 roughness irregularities, as well as all surface waviness. The effects of spindle speed and feed rate on surface roughness were larger than depth of cut for milling operations explained by Zhang et al. (2007). As a starting point for determining cutting parameters, technologists could use the hands on data tables that are furnished in machining data handbooks. In order to highlight the roughness, profile meter traces are recorded on an exaggerated vertical scale. The feasibility study of the minimum quantity lubrication in high-speed end milling stated that the surface roughness in dry and MQL cutting decreases as cutting speed is increased (Liao et al., 2001). It is also noted that in the cutting speed range between 200 m/min and 250 m/min, the application of MQL results in the best surface finish.

2.7.3 Material Removal Rate

Material removal rate is the quantity of material removed in forms of chip during the milling process. According Kishawy et al. (2005) stated that the volumetric material removal rate induced by the silicon hard particles will be lower due to the lowered stress magnitude acting in this region when compared to the tool tip area, allowing for the workpiece material deposit. However higher material removal rate is good, but often maximum removal rate could cause the tool to wear easily and also causes higher surface roughness, hence the lower surface roughness and higher material removal rate must be chosen.

2.8 SUMMARY

This chapter summarized the literature review based on milling process, aluminum alloy 6061-T6 and response surface method. The surface roughness, MRR and tool wear have been selected to evaluate the machining performance of aluminum alloy based on the type of technique used in end milling machine. The experiment will be conducted using coated carbide in order to identify the effect of coating layer to the machining process in minimum quantity lubrication comparing with flooded technique. The prediction and optimization will be developed through response surface method. The experimental detail will be further discussed in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents about the materials used in this experiment according to the properties and selection of the material. In other hand, the experiment set up, the equipment of the machine and the preparation of the workpiece in addition the technique use during performed the experiment. Furthermore, the detail information about design of experiment (DOE) will be discussed in this chapter regarding how to get the good range of parameters used to complete the experiment properly. The performance of minimum quantity lubrication technique using coated carbide cutting tool was studied experimentally by evaluating the effects of cutting speed, feed rate, and depth of cut on surface finish produced. The study was carried out by simultaneously varying the cutting parameters such as cutting speed, feed, and depth of cut by fitting the values in a response surface method. The flow diagram is shown in Figure 3.1.

3.2 MATERIAL PROPERTIES

Aluminum alloy 6061 is one of the most widely used alloys in the industry now. According Cheng et al. (2006) aluminum offers advantages over other materials because of its relatively low density, high recyclability, design flexibility in mass production and economic benefit. Some companies produce 6061 for use in standard and custom, solid and hollow shapes, rod and bar products. Other than that, 6061 is a precipitation hardening aluminium alloy containing magnesium and silicon as its major alloying elements. The flow diagram in Figure 3.1 illustrates the project procedure.

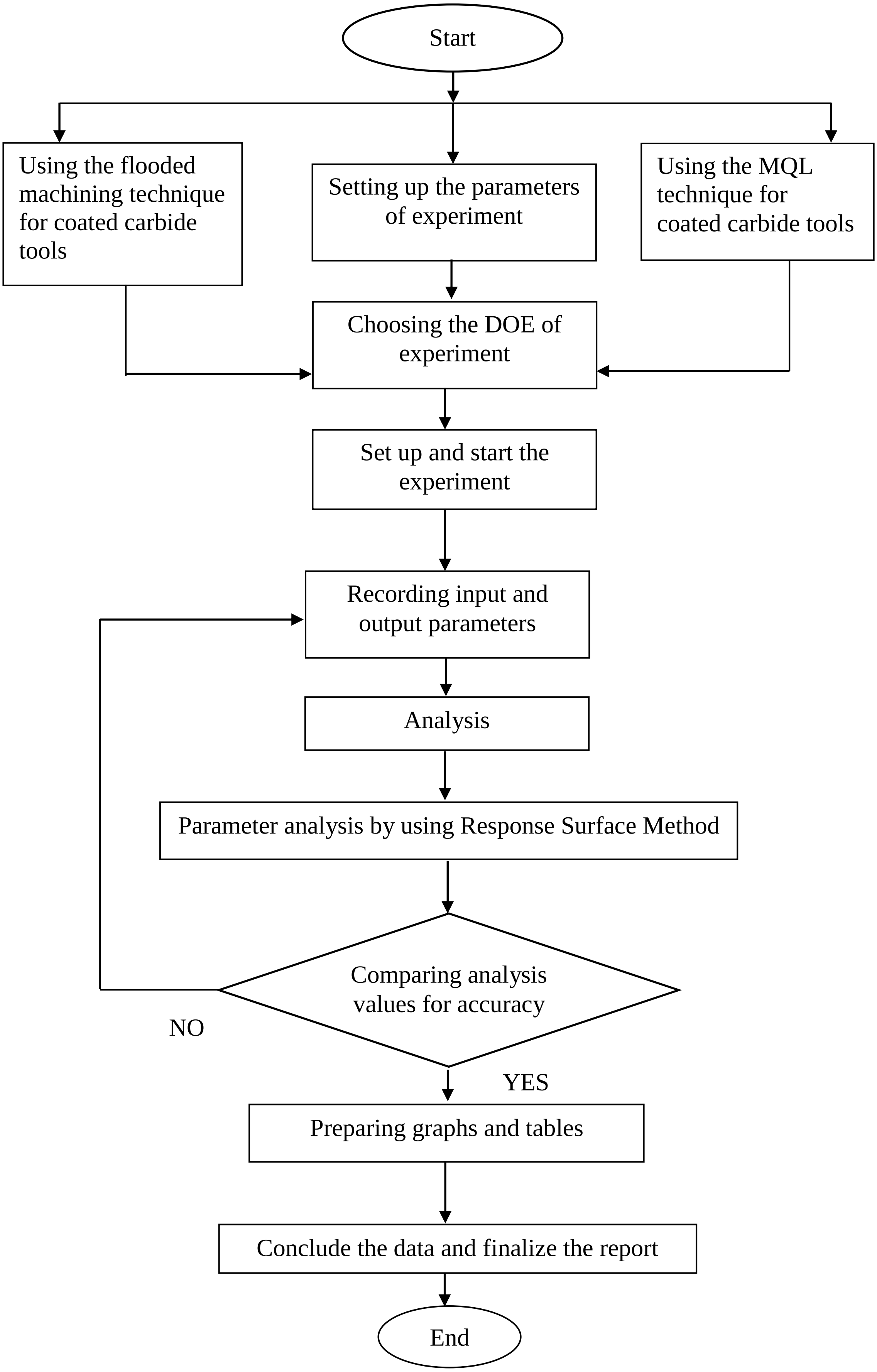


Figure 3.1: Flow Chart of the Study

It has good mechanical properties and exhibits good weld ability. Alloy 6061 have many types such as 6061-0, 6061-T4, 6061-T6 and many more. The mechanical properties of all type of alloy 6061 depend greatly on the temper, or heat treatment, of the material. It is one of the most common alloys of aluminium for general purpose use. Aluminum alloy 6061 commonly used for construction of aircraft structures, such as wings and most usually in homebuilt aircraft. Figure 3.2 shows the workpiece used in this experiment and the dimension for workpiece is 100 mm × 100 mm × 30 mm.

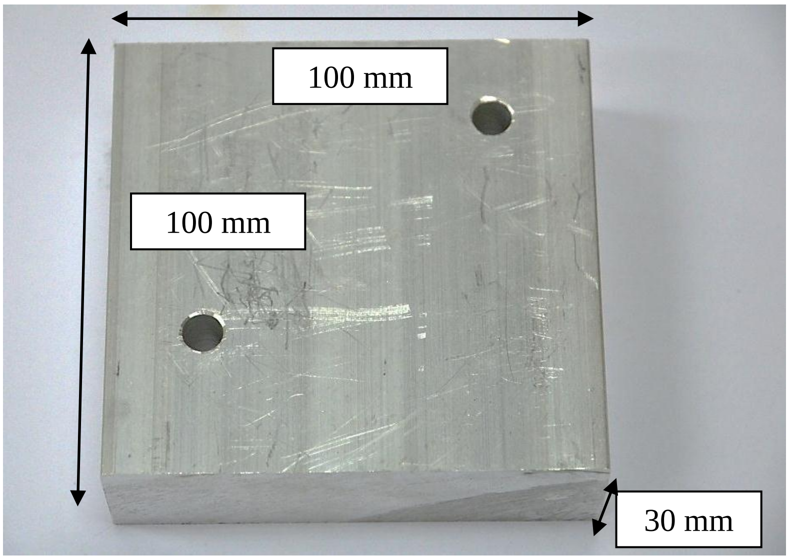


Figure 3.2: Workpiece block.

According Ravi et al. (2011) alloy Al 6061-T6, are some of the most promising candidates for fabricating thermally stable, high-strength and light-weight nanostructured materials through large strain deformation. In thicknesses of 6.35 mm or less, it has elongation of 8 % or more; in thicker sections, it has elongation of 10 %. The chemical composition of the aluminum alloy 6061-T6 workpiece shown in the Table 3.1

Table 3.1: Chemical composition of the aluminum alloy 6061-T6

Al	Cr	Cu	Fe	Mg	Si	Zn
Remainder	0.04-0.35	0.15-0.40	0.7	0.8-1.2	0.40-0.8	0.25

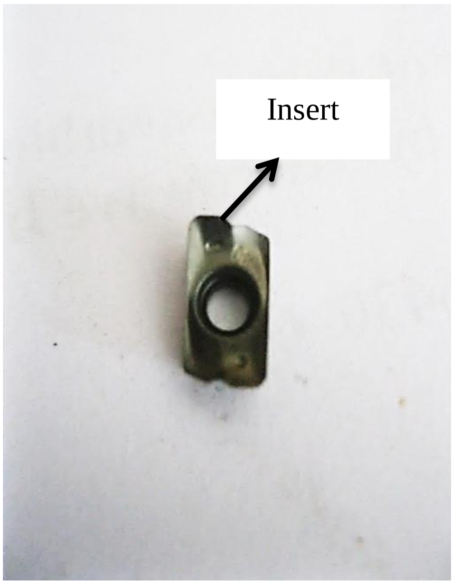
3.3 CUTTING TOOL

The cutting tools used for this experiment are coated carbide cutting tool and the coated carbide used in this experiment is CTP 2235. CTP 2235 is a coated carbide grade with TiAlN coating PVD. Ghani et al. (2004b) stated that coated carbide is suitable for machining because it is possible to employ the carbide and nitride based tool materials at cutting speeds that are so low that mechanical wear predominates. Cutting tool insert is shown in Figure 3.3 and the composition of the cutting tool insert for coated carbide cutting inserts is signified in Table 3.2.

Table 3.2: Composition of the coated carbide inserts.

Type of carbide	Code name	Composition	Coating	Grain size
Coated carbide	CTP 2235	12.5 % of Co, 2.0 % mixed carbide,85.5 % WC	PVD TiA1N	1μm

(a)



(b)

Figure 3.3: (a) tool holder and cutting tool insert, (b) insert coated carbide tool

3.4 MACHINING PARAMETERS

The parameters of this experiment achieve by the best technique which is Design of Experiment (DOE). The parameter for determine depend on the previous literature and the specification and limitation of the machine used. Table 3.3 shows the parameters done by DOE for MQL experiment. The parameter that use in this experiment can be divided in two type, input and output parameters. Table 3.4 shows the input and output parameters done in the machining aluminum alloy 6061-T6.

Table 3.3: Parameters for MQL machining.

	No. of Exp.	**Cutting speed (m/s)**	**Feed rate (mm/rev)**	**Depth of Cut (mm)**	**MQL Flow rate (ml/min)**
Work Piece A	1	5500	318	3	0.48
	2	5300	440	1	0.825
	3	5300	318	1	0.48
	4	5400	379	2	0.9
Work Piece B	5	5400	469.4373	2	0.6525
	6	5300	440	3	0.48
	7	5500	318	3	0.825
	8	5300	318	1	0.825
Work Piece C	9	5548.258	379	2	0.6525
	10	5400	288.5627	2	0.6525
	11	5400	379	2	0.39
	12	5500	440	3	0.825
Work Piece D	13	5251.742	379	2	0.6525
	14	5400	379	2	0.6525
	15	5500	440	1	0.825
	16	5300	318	3	0.825
Work Piece E	17	5400	379	3.482579	0.6525
	18	5300	318	3	0.48
	19	5500	318	1	0.825
	20	5400	379	0.517421	0.6525
Work Piece F	21	5500	440	1	0.48
	22	5300	440	1	0.48
	23	5500	318	1	0.48
	24	5500	440	3	0.48
Work Piece G	25	5300	440	3	0.825
	26	5500	318	3	0.48

Table 3.4: Input and output parameters

Input Parameters	Output Parameters
Cutting speed	Surface roughness
Feed rate	Tool wear
Axial Depth of Cut	Material removal rate

3.4.1 Input Parameters

The input parameter depends on the specification of the end milling machine that use in this experiment. The details for all input parameter are as follows:

Cutting speed: Cutting speed is the speed different between the surface of workpiece operating and the cutting tool. For the milling machining the cutting speed is the speed occur in the outside of edge of milling cutter when the rotating operation is running. The MQL will produce the good surface roughness compared with the dry cutting when increasing the cutting speed (Rahman et al. 2001). The cutting speed in context of milling cutter is defined when the cutting tool rotates at a certain number of revolutions (n) per minute. This gives a specific cutting speed, v_c (or cutting tool speed), measured in (m/min). The formula cutting speed is mentioned in Equation (3.1).

$$V_c = \frac{\eta \times D \times n}{1000} \text{ m/min} \tag{3.1}$$

Feed Rate: Feed rate is the rate at which the workpiece can be fed to a machine. The higher of feed rate the average of workpiece surface roughness will higher (Arumugam et al. (2006). The feed rate for the mm/rev in milling determine by the Equation (3.2).

$$f_r = f_t \times n \times V_c \tag{3.2}$$

where,

f_r = Feed rate in mm/rev

f_t = Feed rate in mm/tooth

n = Number of the teeth of cutter

Axial Depth of Cut: The depth of cut means that the depth of the workpiece when the cutting operation run along it axis. According to Borneman (1983) stated that tool angular position depends on the depth of cut and radius of the cutter. Ghani et al. (2004a) mentioned that the use of high depth of cut combined with high cutting speed and feed rate could cause more severe damage on the cutting edge than at low cutting speed. However, the depth of tool along the radius of workpiece is the radial depth of cut, which is less than the radius of the tool and partially used to make peripheral cut in the work piece.

3.4.2 Output Parameters

Output parameter is the performance characteristic that id obtained from the experiment. The output parameters investigated from this experiment are surface roughness, tool life, tool wear and the chip formation for the technique use. Amin et al. (2007) concluded that the tool wear, tool life, and chip formation can be measured in end milling machining.

Surface Roughness: Surface roughness is most important variable in surface finish. Perthometer use to measure the surface roughness. This is the most common and popular method amongst all is interpreting to average roughness indication. The average roughness (R_a) is the most normally used parameter in surface finish measurement and also known as Arithmetic Average (AA) and Center Line Average (CLA). The average roughness is the area between the roughness profile and its mean line. Figure 3.4 shows the position of the average roughness.

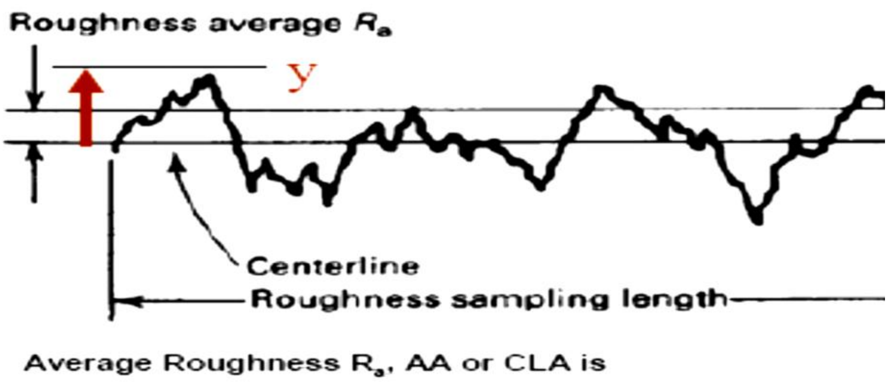


Figure 3.4: Position for average roughness

Surface roughness (R_a) can be written as Equation (3.3):

$$R_a = \frac{1}{L}\int_0^L |Y(x)|\,dx \tag{3.3}$$

Trapezoidal rule normally calculate integral, which can be described as Equation (3.4).

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|Yi| \tag{3.4}$$

In Equation (3.3), R_a is the arithmetic average deviation from the mean line, Y symbolizes for alignment of the profile curve and L is roughness sampling length.

Tool wear: The basic processes involving wear and friction are called tool machining. The wear of a tool takes place while the procedures of cutting are in the process. This minimizes the working span of the cutting tool and also results in enhanced roughness of the surface of the machine (Zhang et al., 2001). For example type of tool wear is the flank tool wear. These types occur between flank face and the work or the flank tool wear occur when the part of tool wear in contact with the surface of workpiece. Figure 3.5 shows the flank tool wear for the technique use in end milling.

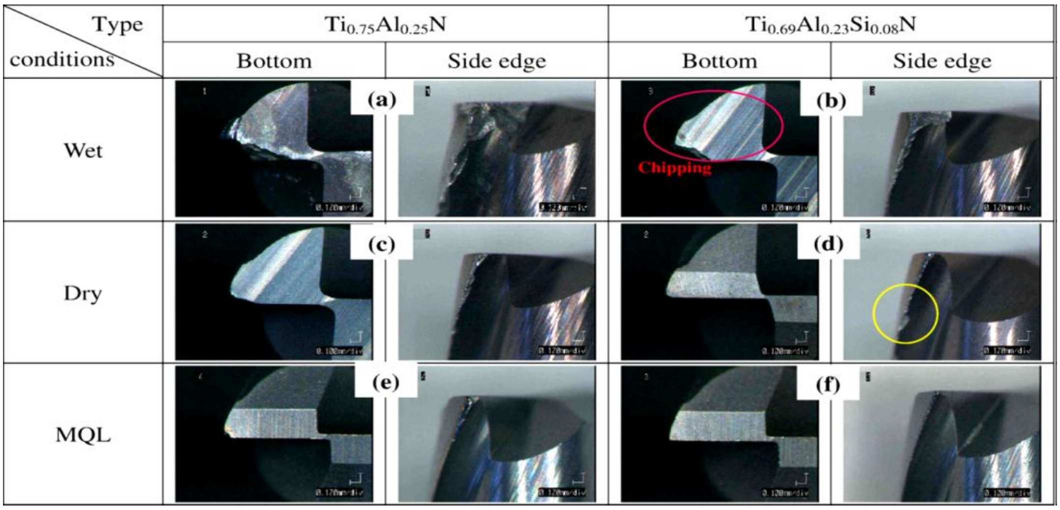


Figure 3.5: Tool wear depend on the technique use.

Tool Life: The tool life refers the useful life of tool. The tool failure criterion be used depends upon the requirements of the component being produced. In roughing operations, a specified increase in cutting force or power requirements over the initial value may be taken as failure criteria while in finishing operations. Attanasio et al. (2006) conclude that a rise in feed rate always causes a reduction in tool life time, but the flank MQL mean life lines lie consistently above the others. However, the tool should not be allowable to undergo complete failure in roughing operations to avoid the possible damage to the component and the total loss of the cutting tool. The end milling applications, the wear characteristic is determined based on ISO 8688-2:1989 (E) while ISO Geneva. Kadirgama et al. (2011) suggested a standard of 0.3 mm for uniform wear criterion, maximum criterion of 0.6 mm and severe flaking or chipping greater than 0.4 mm of the width takes place at the time in end milling. The experimental observations, Taylor proposed a tool life equation and the formula show by Equation (3.5).

$$V_c T^n = C \tag{3.5}$$

where:
V_c is cutting speed,
T is tool life (minutes),
n is an exponent for the conditions tested, and
C is a Taylor's constant for the unaccounted variables

Material Removal Rate: Material removal rate means how much material that can be removed under operation machining. In the milling machining operation the calculation for calculate of material removal rate is different. Figure 3.6 and 3.7 show the movement of tool in horizontal and vertical milling machine, respectively.

Cutting Speed:

$$N = \frac{kV}{\pi D} \tag{3.6}$$

Table Feed Rate:

$$f_m = f_t \times N \times n \tag{3.7}$$

Material Removal Rate:

$$MRR = \frac{Vol.Removed}{CT} = \frac{L \times W \times t}{CT} = W \times t \times f_m \tag{3.8}$$

where:

N: RPM of Cutter

n: Number of Teeth on Cutter

W: Width of cut (may be full cutter or partial cutter)

t: depth of cut

V: cutting speed (a Handbook value)

L: Length of pass or cut

f_m: Table (machine) Feed

f_t: feed/tooth of cutter (a Handbook value)

D: Cutter Diamete

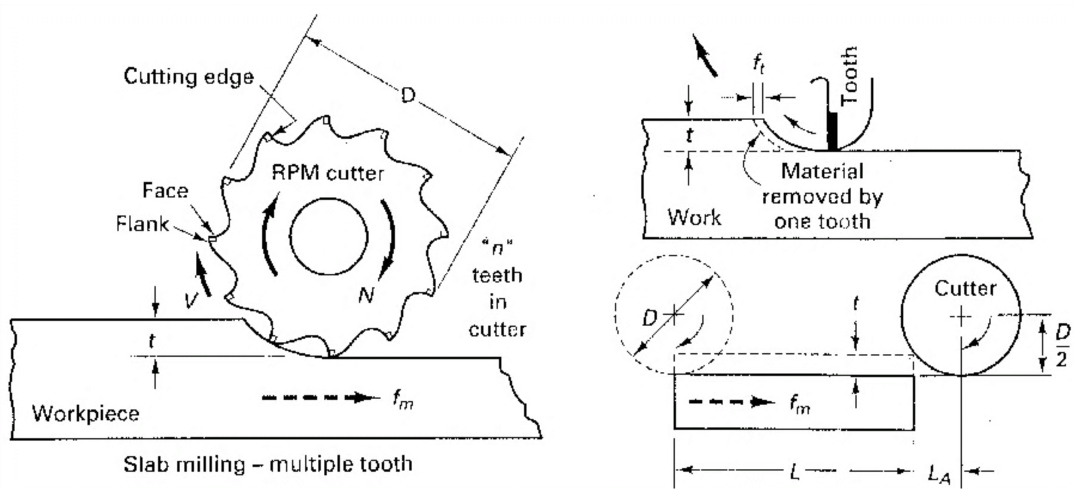


Figure 3.6: The movement of tool in horizontal milling machine.

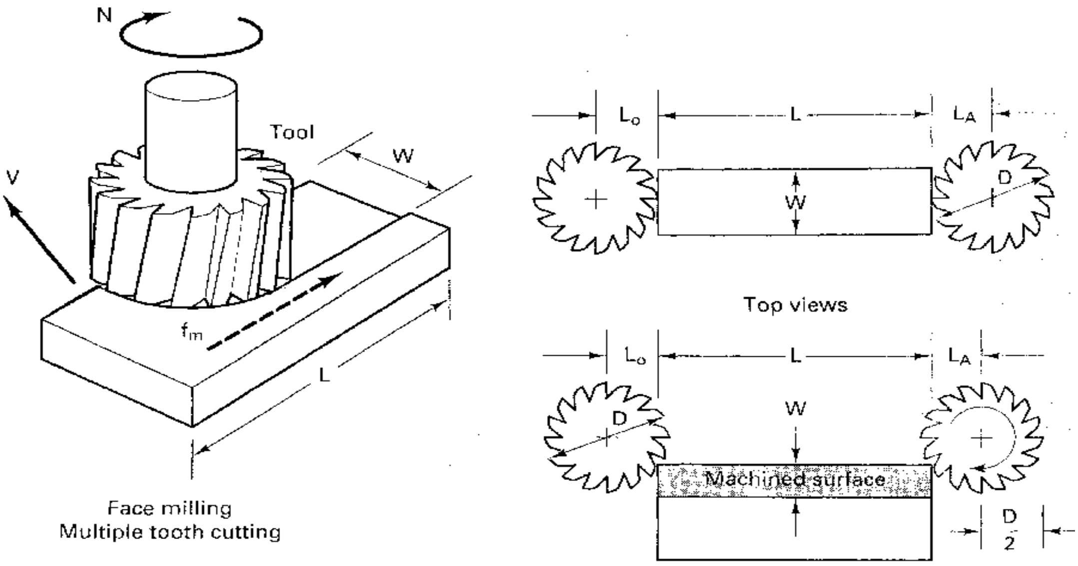


Figure 3.7: The movement of tool in vertical milling machine.

3.5 EXPERIMENT SET UP

For the experiment, HAAS VF-6 machine tool is used. The technique used in this experiment is comparison the output parameter by using minimum quantity lubrication and flooded. Figure 3.8 shows the CNC milling machine, HAAS VF-6 and the requirement for this machining is 8100 rpm for the maximum cutting speed and 15.7 m/min maximum feed rate. The complete specification is shown in Table 3.5.

Figure 3.8: CNC milling machine HAAS VF-6

The workpiece block is locked tightly on the table of CNC milling. It is very important to ensure that the workpiece block not loose when the experiment is running in high spindle speed. CNC is applied to cut the workpiece regarding the input parameters that have been done using design of experiment. After this, the cutting done and for each cutting the workpiece block will be weighed. An advanced optical video computing system is used to estimate the effectiveness of the cutting tool. The tool holder is removed from the panel of the testing machine, during the measurement of the operation.

Table 3.5: The specification for CNC milling machine HAAS VF-6

TRAVELS	**Metric**
X Axis	1626 mm
Y Axis	813 mm
Z Axis	762 mm
Spindle Nose to Table (~ min)	102 mm
Spindle Nose to Table (~ max)	864 mm
TABLE	**Metric**
Length	1626 mm
Width	711 mm
Max Weight on Table (evenly distributed)	1814 kg
SPINDLE	**Metric**
Max Rating	22.4 kW
Max Speed	8100 rpm
Max Torque	122 Nm @ 2000 rpm
Cooling	Liquid Cooled
FEEDRATES	**Metric**
Rapids on X	13.7 m/min
Rapids on Y	15.2 m/min
Rapids on Z	15.2 m/min
Max Cutting	12.7 m/min

3.6 DATA COLLECTION

Developing mathematical model: The approximating function by constituting two variables is called a second-order model as shown in Equation (3.10).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon \qquad (3.10)$$

where *Y* represent the corresponding responses such as *SR*, *TL*, *CF*, that yield by the several variables. X_j represents the input variables such as F_R, A_D and C_S; X_j^2 is square of the input variables, and $X_j X_i$ is multiplication term of the input variables. The estimators β_0, β_j, β_{jj} and β_{ij} are the second order regression coefficients.

Measuring Surface Roughness: To measure the surface roughness the equipment used was Marsurf PS1 which given the value of surface roughness in R_a. The cutting piece of workpiece will be clean up first by polishing and grinding processes to ensure reliable surface roughness can get a good result. Figure 3.9 shows the equipment that use for measuring surface roughness.

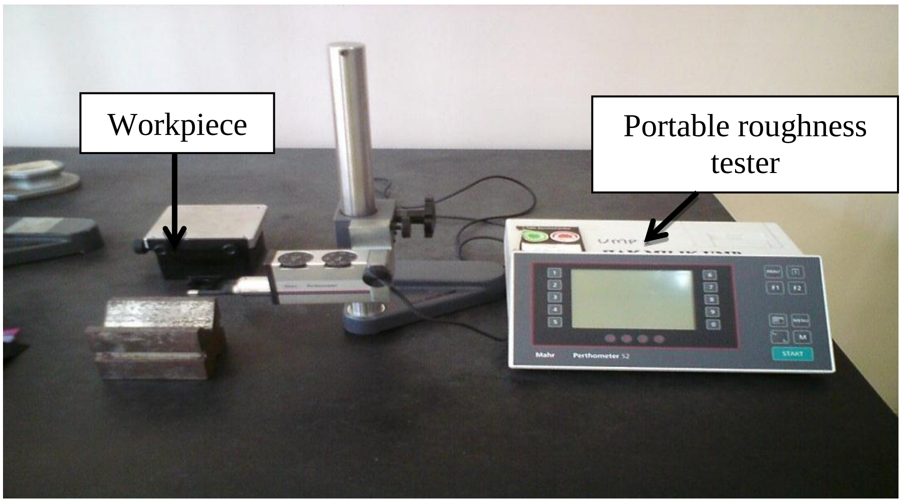


Figure 3.9: Portable roughness tester model MarSurf PS1

Tool Wear Measuring: The tool wear measure for each cutting of workpiece block. The tool wears measure by Optical video measuring system model SOV-2010 (N/A) and as shown in Figure 3.10. The type of tool wear usually detect in measuring is flank wear. The flank wear were looking for a different modes and the measured take in seven reading.

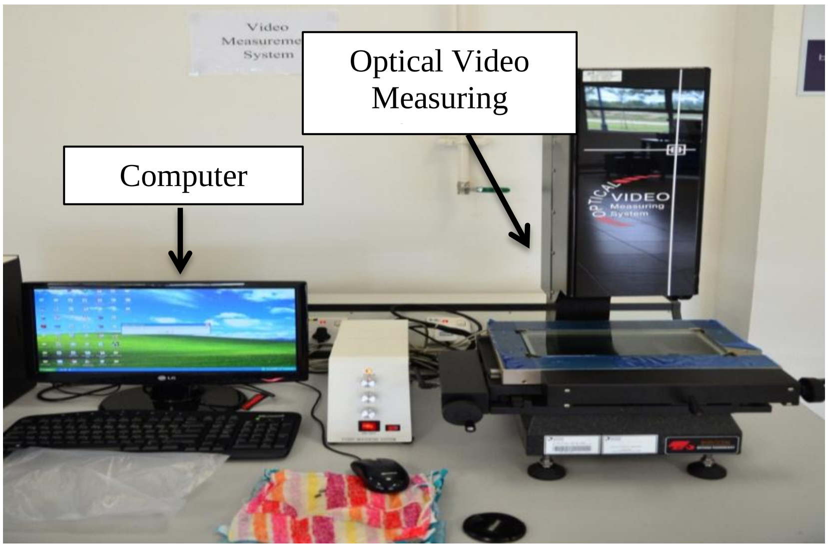


Figure 3.10: Optical video measuring system.

3.7 SUMMARY

This chapter explained the technique used in collecting data by end milling process. Besides that, this chapter described the detail about experiment procedure according to operate the end milling machine until collect the data. After collecting the data the analysis will be done and these approaches will work will be explained in the upcoming chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the experimental result and develop a mathematical model by using the response surface method (RSM). The process requires an experimental analysis by using machining the minimum quantity lubrication that is performed on AA6061-T6 using coated carbide tool and CNC end milling machine and the experimental result with be flooded technique. The relationship between input variables which are feed rate, depth of cut, cutting speed and MQL flow rate and output parameters which are the surface roughness, tool wear and material removal rate will generate by the mathematical model. The optimization value of the experiment is done by statistical method.

4.2 DESIGN OF EXPERIMENTS

Machining variables choose for the study of this research is cutting speed, feed rate, depth of cut and the MWL flow rate. Central composite design approach of response surface methodology is used for the design of experiments in order to find the effects of parameters and the combination of the parameters. Five levels of machining variables are selected for the MQL and flooded coated carbide cutting tool CTP 2235 is shown in Table 4.1 and 4.2, respectively.

Table 4.1: Design of experiment matrix for MQL conditions

Factors	Levels				
	1	**2**	**3**	**4**	**5**
Cutting speed (rpm)	5252	5300	5400	5500	5548
Depth of cut (mm)	0.52	1.0	2.0	3.0	3.5
Feed rate f_z (mm/min)	288	318	379	440	469
MQL flow rate (ml/min/nozzle[*])	0.013	0.016	0.022	0.0275	0.030

Table 4.2.: Design of experiment matrix for flooded conditions

Factors	Levels				
	1	**2**	**3**	**4**	**5**
Cutting speed (rpm)	5252	5300	5400	5500	5548
Depth of cut (mm)	0.52	1.0	2.0	3.0	3.5
Feed rate (mm/min)	288	318	379	440	469

4.3 SURFACE ROUGHNESS

4.3.1 Development of Mathematical Model

RSM has been used to develop the mathematical modelling and to optimize the machining parameters for the experimental by using technique of minimum quantity lubrication using coated carbide tool (CTP 2235). First order and second order of RSM model has been developed based on surface roughness, material removal rate and tool wear results. Using the RSM model it is potential to find those factors will influence the output parameter. This is basically done to improve the efficiency levels of the response surface found to be influenced by the different parameters. The first order mathematical model is expressed as Equation (4.1).

$$y = a \times \text{Depth of cut} + b \times \text{Cutting speed} + c \times \text{Feed rate} + d \times \text{MQL flow rate}. \quad (4.1)$$

where *a*, *b*, *c* and *d* are the constants and *y* is the response.

Equation (4.1) can also be written as Equation (4.2):

$$y = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \tag{4.2}$$

where, y is the response, x_0 = 1(variable), x_1=depth of cut, x_2 =cutting speed, and x_3 = feed rate, x_4 = MQL flow rate. β_0 = D and β_1, β_2, β_3 and β_4 are the model parameters.

Equation (4.3) is the presentation of the second-order model:

$$\begin{aligned} y'' = {} & \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x^2{}_1 + \beta_{22} x^2{}_2 \\ & + \beta_{33} x^2{}_3 + \beta_{44} x^2{}_4 + \beta_{11} x_1 x_2 + \beta_{12} x_1 x_3 + \beta_{13} x_1 x_4 \\ & + \beta_{14} x_2 x_3 + \beta_{15} x_2 x_4 + \beta_{16} x_3 x_4 \end{aligned} \tag{4.3}$$

The first order model had been considered efficient for use and due to some extended variable it was essential to develop the second-order model. Hence, the second order models for coated carbide cutting tool insert CTP 2235 for MQL and flooded has been identified in the quadratic equation as Equation (4.4) and (4.5) respectively:

For MQL condition:

$$\begin{aligned} y'' = {} & -234.69141 + 0.18227 x_1 + 0.09239 x_2 + 0.065367 x_3 - 11.02995\, x_4 \\ & - 0.18559 x_1^2 - 8.98248\text{E}-06 x_2^2 + 0.00002 x_3^2 + 4.04478\, x_4^2 \\ & + 0.00013 x_1 x_2 - 0.00047 x_1 x_3 + 0.23333 x_1 x_4 + 0.00001\, x_2 x_3 \\ & + 0.00164 x_2 x_4 - 0.01234\, x_3 x_4 \end{aligned} \tag{4.4}$$

For flooded condition:

$$\begin{aligned} y'' = {} & 595.43799 - 4.02575 x_1 - 0.21094 x_2 - 0.11049 x_3 + 0.00077 x_1 x_2 \\ & + 0.00084 x_1 x_3 + 0.00002\, x_2 x_3 - 0.04159 x_1^2 + 0.00001 x_2^2 - 0.00001 x_3^2 \end{aligned} \tag{4.5}$$

Table 4.3 presents the results of the analysis of the variances of the second order model surface roughness for MQL and the flooded. The RSM has provided the confidence level of 95 % same like the first order. According to Table 4.3, both models have *P*-values of linear source which are less than the α-value (0.05) and the square source is less than α-value stating that they are significant. The lack of fit values for MQL and flooded of 0.285 and 0.544 respectively have been found to be unfit and insignificant since they are higher than the α-level. The interaction effects in the model show also significance. Only the interaction of the feed rate by MQL flow rate shows significance with a p-value of 0.001, meaning that the effect of feed rate on surface roughness depends on the MQL flow rate. R square of this experiment states that the model explains nearly 98.69 % of the variation in the data of surface roughness of coated carbide cutting tool using MQL technique while the R square adjusts to make it more similar over models with different numbers of parameters.

Table 4.3: Variance analysis for the second order model of the surface roughness MQL and flooded

Source	**MQL**			**Flooded**		
	DOF	**F-value**	**P-value**	**DOF**	**F-value**	**P-value**
Regression	14	44.96	0.000	9	76.43	0.000
Linear	4	12.36	0.007	3	52.09	0.003
Square	4	40.74	0.030	3	31.83	0.003
Interaction	6	17.74	0.006	3	28.18	0.057
Residual Error	11			10		
Lack of Fit	10	9.22	0.285	5	4.81	0.544
Pure Error	1			5		
Total	25			19		

DF= Degree of freedom’ R-Square = 98.69 % (MQL); R-Square = 95.58 % (Flooded)

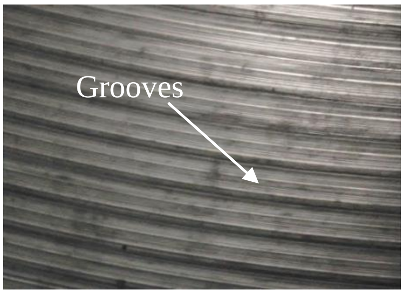
Table 4.4 and 4.5 shows the experimental and predicted result RSM value by surface roughness with percentage of absolute relative error for flooded and MQL condition. The minimum errors have been observed 1.451 % and the maximum error that has been seen is 10.534 % respectively for the flooded condition. The minimum and maximum errors have been observed 0.269 % and 8.824 % for the MQL condition.

Figure 4.1 shows that the surface condition of the machined aluminium alloy 6061T6 which had been taken using the optical microscope. The flooded machined work piece has a wavier pattern, composed of more valleys and coarser surface finish compared to the minimum quantity lubrication surface finish. Comparing both MQL and flooded in terms of cutting speed, both are associated with each other's' factor but MQL has a better result where the points in the diagram can be seen to be the lowest in surface roughness at every value of speed. That means the surface roughness value is more desired in MQL compared to flooded machining. The images also show that the flooded machining shows that the surface roughness increases when the cutting speed increases while the surface roughness of MQL decreases when the cutting speed increase.

Table 4.4: Experimental and predicted results RSM of surface roughness for MQL

No	Exp.Cutting Condition				Exp. result	Predicted result	Absolute Error (%)
	CS	FR	DOC	MF	MQL	MQL	MQL
1	5500	318	3	0.48	0.958	1.014	5.523
2	5300	440	1	0.825	0.296	0.272	8.824
3	5300	318	1	0.48	0.845	0.792	6.692
4	5400	379	2	0.9	0.903	0.927	2.589
5	5400	469	2	0.6525	1.132	1.177	3.823
6	5300	440	3	0.48	1.175	1.179	0.339
7	5500	318	3	0.825	1.098	1.034	6.190
8	5300	318	1	0.825	0.486	0.523	7.075
9	5548	379	2	0.6525	0.816	0.86	5.116
10	5400	289	2	0.6525	1.033	1.042	0.864
11	5400	379	2	0.39	1.505	1.535	1.954
12	5500	440	3	0.825	0.906	0.941	3.719
13	5252	379	2	0.6525	0.592	0.602	1.661
14	5400	379	2	0.6525	0.971	0.938	3.518
15	5500	440	1	0.825	0.606	0.617	1.783
16	5300	318	3	0.825	0.875	0.91	3.846
17	5400	379	3.5	0.6525	0.745	0.743	0.269
18	5300	318	3	0.48	1.034	1.011	2.275
19	5500	318	1	0.825	0.623	0.601	3.661
20	5400	379	0.5	0.6525	0.322	0.336	4.167
21	5500	440	1	0.48	1.346	1.293	4.099
22	5300	440	1	0.48	1.017	1.069	4.864
23	5500	318	1	0.48	0.749	0.75	0.133
24	5500	440	3	0.48	1.496	1.448	3.315
25	5400	379	2	0.6525	1.001	0.938	6.716
26	5300	440	3	0.825	0.563	0.551	2.178

Note: FR= Feed rate (mm/tooth), DOC=Depth of Cut (mm), CS=Cutting speed (rpm), MF=MQL flow rate (ml/min)



(a) MQL

(b) Flooded

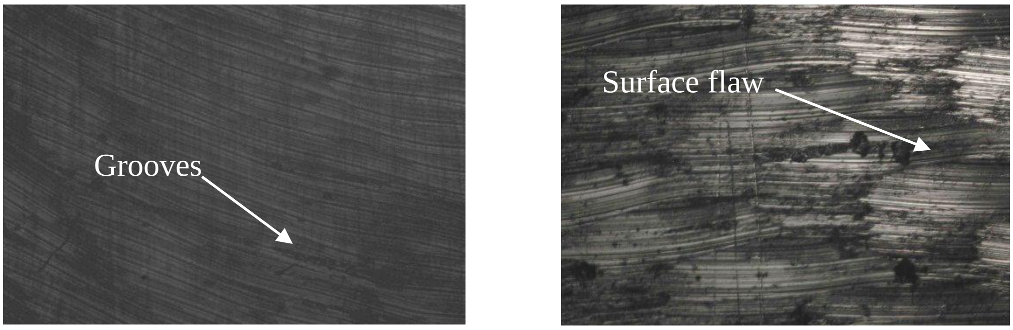
Figure 4.1: Image of surface roughness for maximum cutting speed (a) MQL (b) flooded conditions

Table 4.5: Experimental and predicted results RSM of surface roughness for flooded

No	**Exp.Cutting Conditions**			**Exp. result**	**Predicted result**	**Absolute Error (%)**
	CS	**FR**	**DOC**	**flooded**	**flooded**	**flooded**
1	5400	379	2	0.83	0.889	2.468
2	5300	318	1	0.881	0.951	1.850
3	5400	379	2	0.799	0.889	6.110
4	5500	318	3	1.234	1.179	1.201
5	5300	440	3	0.992	1.107	2.362
6	5500	440	1	0.67	0.629	5.181
7	5500	318	1	0.544	0.498	5.837
8	5400	379	2	0.908	0.889	6.698
9	5400	379	2	0.867	0.889	1.880
10	5300	440	1	0.496	0.529	4.421
11	5300	318	3	1.202	1.321	2.197
12	5500	440	3	1.538	1.516	0.646
13	5400	288	2	0.773	0.744	0.000
14	5548	379	2	1.223	1.367	1.846
15	5400	379	2	0.798	0.889	6.228
16	5400	379	3.5	1.363	1.292	4.125
17	5252	379	2	1.112	1.403	1.079
18	5400	379	0.5	0.288	0.265	9.943
19	5400	379	2	0.913	0.889	7.286
20	5400	469	2	0.697	0.676	1.554

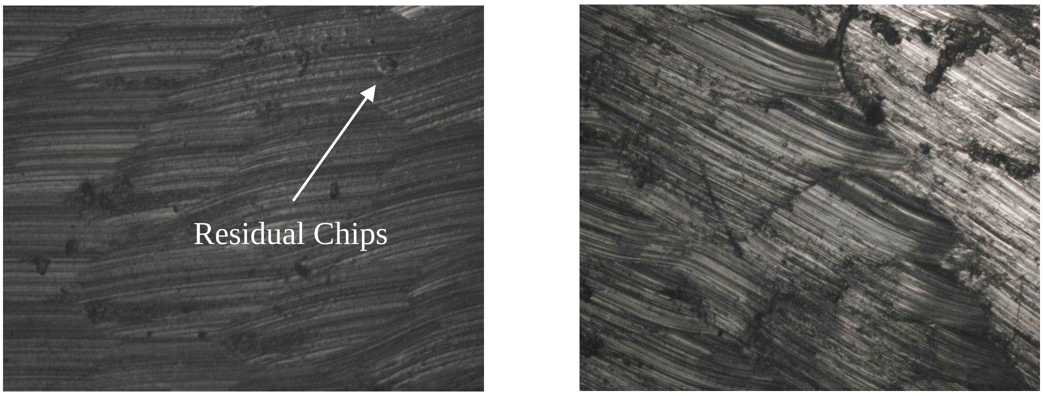
Note: FR= Feed rate (mm/tooth), DOC=Depth of Cut (mm), CS=Cutting speed (rpm)

Figure 4.2 shows the comparing MQL and flooded in terms of feed rate, both are associated with each other's' factor but MQL has a better result where the points in the diagram can be seen to be the lowest in surface roughness compare to the flooded surface roughness. That means the surface roughness value is more desired in MQL while the flooded shows the highest surface roughness value. The flooded machined work piece has a wavier pattern, composed of more valleys and coarser surface finish compared to the minimum quantity lubrication surface finish. The surface finish of minimum quantity lubrication is smoother and has minimal swirl marks compared to the flooded machining.



(a) MQL (b) Flooded

Figure 4.2: Image of surface roughness for maximum feed rate (a) MQL (b) flooded conditions



(a) MQL (b) Flooded

Figure 4.3: Image of surface roughness for maximum depth of cut (a) MQL (b) flooded conditions

Figure 4.3 shows the comparing surface finish of aluminum alloy 6061T6 in term of depth of cut by using MQL machining and flooded machining taken using the optical microscope. The flooded machined surface finish has a wavier pattern, composed of more valleys compared to the minimum quantity lubrication surface finish. The surface finish of minimum quantity lubrication is smoother compared to the flooded machining. As the depth of cut increases, the surface finishes of aluminium alloy become rougher. The MQL has uniform swirled and bright buffed finish while for flooded machining produced a large-pattern matte finish.

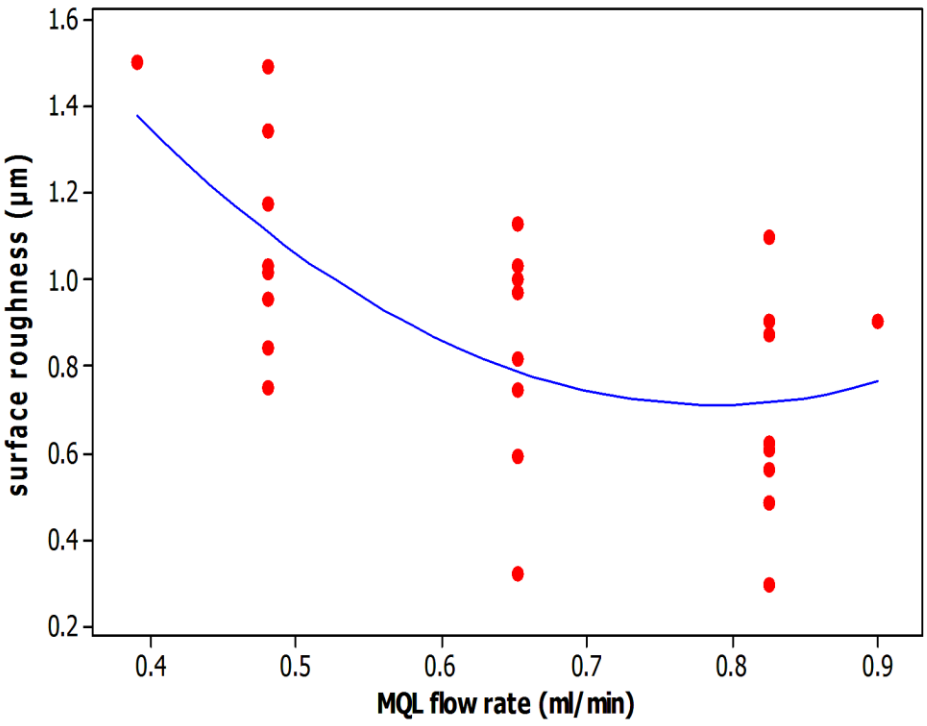
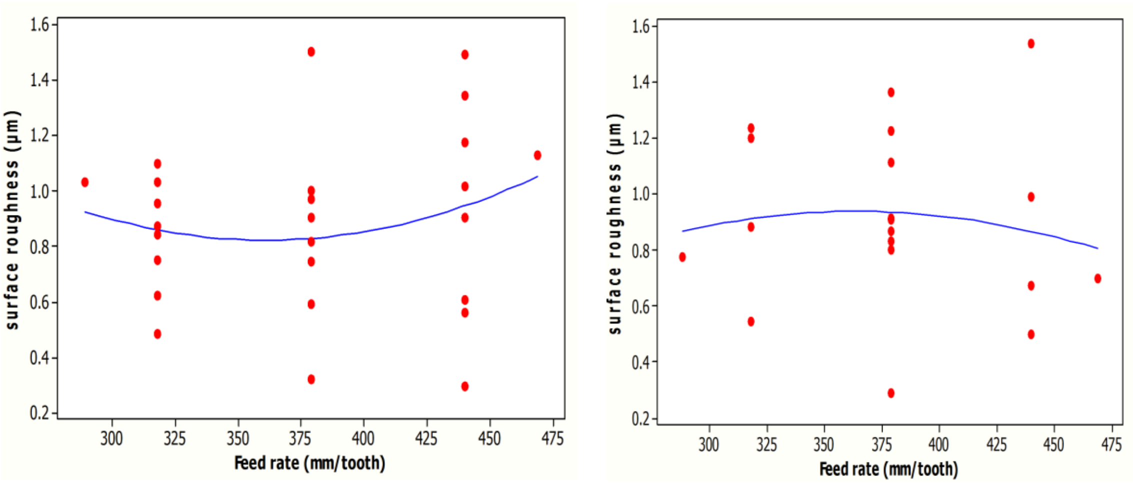


Figure 4.4: Surface roughness versus MQL

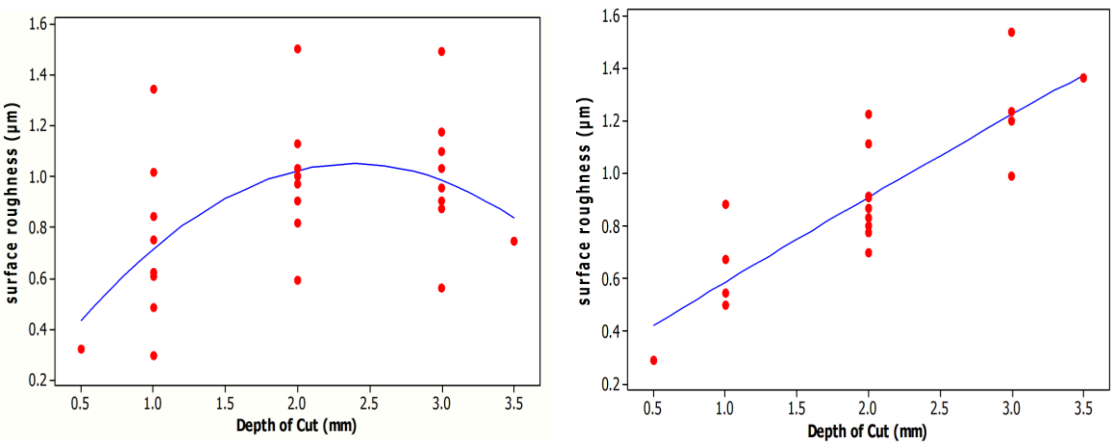
Figure 4.4 shows the relationship between surface roughness versus MQL flow rate for coated carbide 2235, as the flow rate increase, it can be seen that the surface roughness is significantly decreasing but just before the end, it undergoes a slight increase. The maximum surface roughness recorded is 1.4 mm. The feasibility study of the minimum quantity lubrication in high-speed end milling stated that the surface roughness in dry and MQL decreases as cutting speed is increased (Liao et al., 2007).

Figure 4.5 shows the relationship between surface roughness and feed rate for coated carbide 2235 with MQL and flooded. In the MQL condition, if the slow feed rate is being used then it is observed that the surface roughness value is also lower. It can be seen that it started with a minor decrease for the MQL and the maximum value of surface roughness is 0.9 µm. On the other hand for flooded, the opposite pattern can be observed as it started with increase and decrease of surface roughness as the feed rate value increase followed by a uniform decrement. The maximum surface roughness is 0.9 µm



(a) MQL condition (b) Flooded condition

Figure 4.5: Surface roughness versus feed rate using (a) MQL (b) flooded

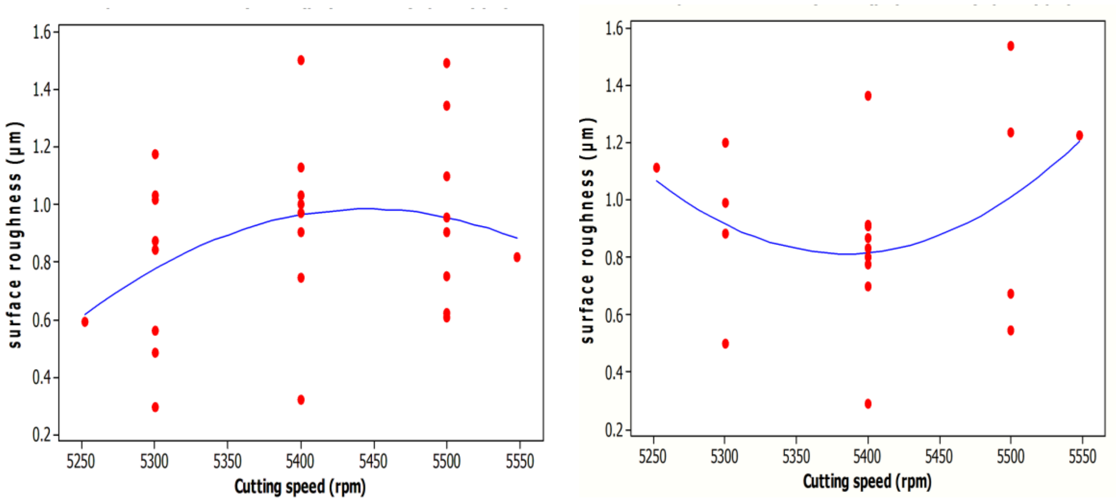


(a) MQL condition (b) Flooded condition

Figure 4.6: Surface roughness versus depth of cut for (a) MQL (b) flooded

Figure 4.6 shows the relationship between surface roughness and depth of cut for coated carbide 2235 with MQL and flooded. We can see that as the depth of cut increase, there is a major increase of surface roughness at the beginning followed by a uniform decrement at the end for the MQL. The effects of cutting speed and feed rate on surface roughness were larger than depth of cut for milling operations explained by Zhang et al., (2007). The maximum surface roughness is 1 µm. For flooded, a significant increase of surface roughness can be observed as the depth of cut increases. The maximum surface roughness recorded is 1.3 µm.

Figure 4.7 shows the surface roughness versus cutting speed coated carbide for MQL and flooded. For the MQL, it started with minor increase and then followed by a uniform decrement as the cutting speed increase. The maximum surface roughness is 0.9 µm. For flooded, the same pattern can be observed except the increment and decrement is smaller in value. The maximum surface roughness recorded is 0.84 µm.



(a) MQL condition (b) Flooded condition

Figure 4.7: Surface roughness versus cutting speed for (a) MQL (b) flooded

4.4 MATERIAL REMOVAL RATE

4.4.1 Mathematical Model

The first order model had been considered efficient for use and due to some extended variable it was essential to develop the second-order model. Hence, the second order models for coated carbide cutting tool insert CTP 2235 for MQL and flooded by material removal rate has been identified as Equation (4.6) and (4.7), respectively.

For MQL condition:

$$y'' = 703017.71 + 14530.86x_1 - 275.94x_2 + 226.90x_3 - 40117.41x_4 - 544.42x_1^2 + 0.02x_2^2 - 0.01x_3^2 - 3463.75x_4^2 - 2.27x_1x_2 + 9.29x_1x_3 + 1320.32x_1x_4 - 0.03x_2x_3 + 7.37x_2x_4 + 3.05x_3x_4 \quad (4.6)$$

For flooded condition:

$$y'' = 192459.99 - 8269.04x_1 - 40.69x_2 - 417.66x_3 + 1.91x_1x_2 + 7.36x_1x_3 + 0.07x_2x_3 - 200.71x_1^2 + 0.001x_2^2 + 0.04x_3^2 \quad (4.7)$$

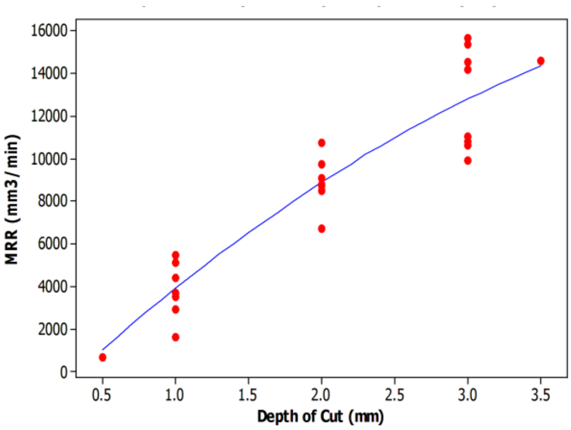
Table 4.6 presents the results of the analysis of the variances of the second order model material removal rate for MQL and the flooded. The RSM has provided the confidence level of 95% same like the first order. According the Table 4.6, both models have *P*-values of linear source which are more than the α-value (0.05) and the square source is less than α-value stating that they are significant. The lack of fit values for MQL and flooded of 0.078 and 0.063 respectively have been found to be unfit and insignificant since they are higher than the α-level. The interaction effects in the model show also significance. R square of this experiment states that the model explains nearly 98.58 % of the variation in the data of material removal rate of coated carbide cutting tool using MQL technique while the R square adjusts to make it more similar over models with different numbers of parameters.

Table 4.6: Variance analysis for second orders MRR for MQL and flooded

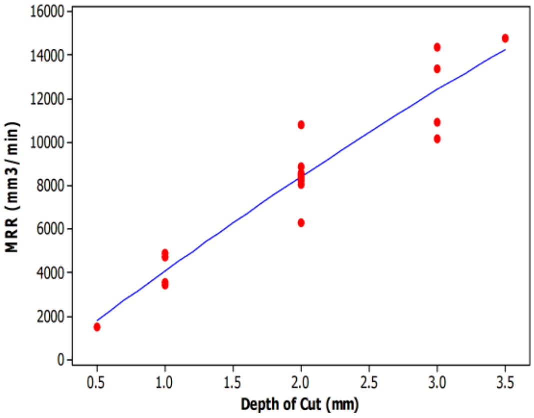
Source	**MQL**			**Flooded**		
	DOF	**F-value**	**P-value**	**DOF**	**F-value**	**P-value**
Regression	14	139.63	0.000	9	38.95	0.000
Linear	4	3.17	0.034	3	0.92	0.173
Square	4	3.85	0.023	3	0.50	0.280
Interaction	6	5.55	0.002	3	3.52	0.009
Residual Error	11			10		
Lack of Fit	10	134.21	0.078	5	0.35	0.063
Pure Error	1			5		
Total	25			19		

DF= Degree of freedom’ R-Square = 98.58% (MQL); R-Square = 97.48 % (Flooded)

Figure 4.8 shows the relationship between material removal rate and depth of cut for coated carbide 2235 with MQL and flooded. It can see that it started with a increasing for the MQL condition and the maximum value of material removal rate is 14000 (mm^3/min). On the other hand for flooded, the opposite pattern can be observed as same with the MQL pattern and increase of material removal rate as the depth of cut value increase. The maximum material removal rate is 13800 (mm^3/min).



(a) MQL condition



(b) Flooded condition

Figure 4.8: MRR versus depth of cut for (a) MQL (b) flooded

Table 4.7 and 4.8 show the experimental and predicted result RSM value by material removal rate with percentage of absolute relative error for MQL and flooded condition in the second order. The minimum errors have been observed 0.079 % and the maximum error that has been seen is 10.379 % respectively for the MQL condition. The minimum errors have been observed 0.024 % and the maximum error that has been seen is 6.311 % for the flooded condition.

Table 4.7: Experimental results RSM second order material removal rate predicted values for flooded

No	Exp.Cutting Condition			Exp. result	Predicted result	Absolute Error (%)
	CS	**FR**	**DOC**	**flooded**	**flooded**	**flooded**
1	5400	379	2	8868.1	8511.297	4.023
2	5300	318	1	3422.8	3206.782	6.311
3	5400	379	2	8217.8	8511.297	3.571
4	5500	318	3	10913.1	10673.704	2.194
5	5300	440	3	14413.6	14347.982	0.455
6	5500	440	1	4722.2	4624.489	2.069
7	5500	318	1	3522.0	3630.319	3.075
8	5400	379	2	8454.2	8511.297	0.675
9	5400	379	2	8572.5	8511.297	0.713
10	5300	440	1	4914.3	5223.535	6.293
11	5300	318	3	10188.9	10356.334	1.643
12	5500	440	3	13384.0	13669.769	2.135
13	5400	288	2	6319.4	6462.488	2.264
14	5548	379	2	8040.4	8038.620	0.022
15	5400	379	2	8406.9	8511.297	1.242
16	5400	379	3.5	14780.1	14706.006	0.501
17	5252	379	2	8371.5	8268.608	1.229
18	5400	379	0.5	1513.5	1482.981	2.016
19	5400	379	2	8513.4	8511.297	0.024
20	5400	469	2	10803.2	10555.437	2.293

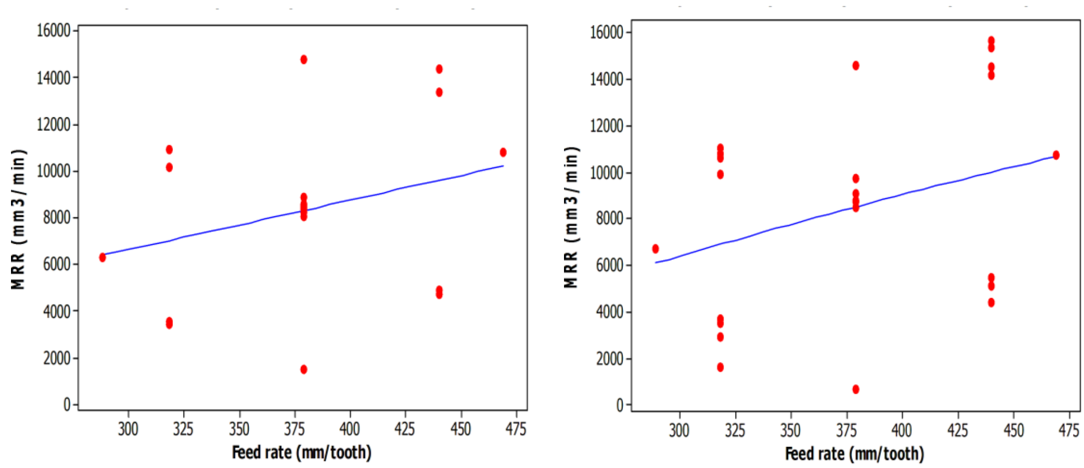
Note: FR= Feed rate (mm/tooth), DOC=Depth of Cut (mm), CS=Cutting speed (rpm)

Figure 4.9 shows the relationship between material removal rate and feed rate for coated carbide 2235 with MQL and flooded. It is observed that it started with a minor increase. The maximum value of feed rate is 475 mm/rev with the maximum material removal rate is 11000 (mm^3/min). On the other hand for flooded, the same pattern can be observed as it started with increasing of material removal rate as the feed rate value increase. The maximum material removal rate is 10000 (mm^3/min) and the maximum feed rate for flooded is 460 mm/rev. Figure 4.10 shows the relationship between material removal rate and cutting speed for coated carbide 2235 with MQL and flooded. It is observed that it started with a minor decrease for the MQL condition with the maximum value of material removal rate is 9000 (mm^3/min). On the other hand for flooded, the opposite pattern can be observed as it started with increasing and decrease of material removal rate as the cutting speed value increase followed by a uniform decrement.

Table 4.8: Experimental results RSM second order material removal rate predicted values for MQL

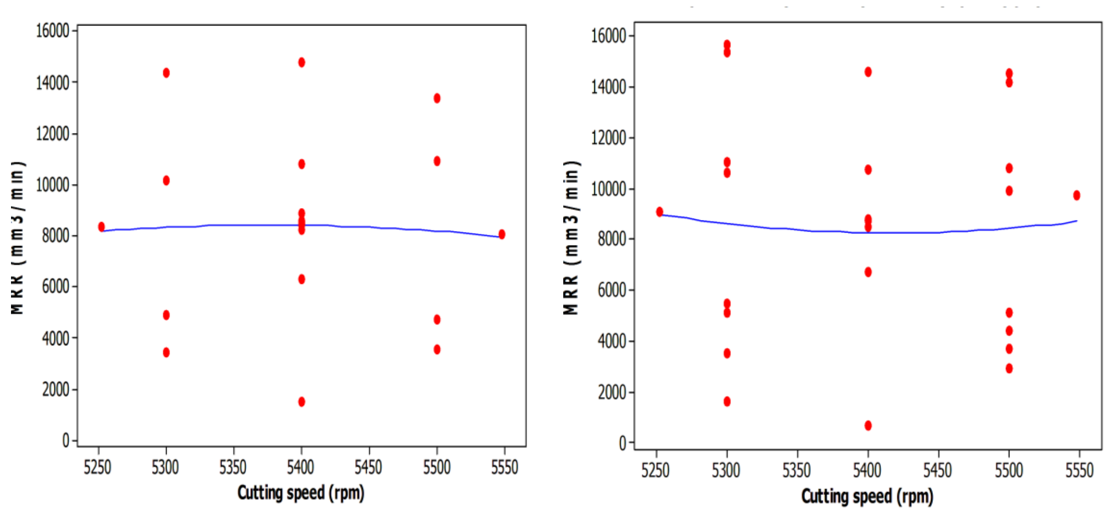
No	Exp.Cutting Condition				Exp. result	Predicted result	Absolute Error (%)
	CS	FR	DOC	MF	MQL	MQL	MQL
1	5500	318	3	0.48	9885.313	10477.336	5.651
2	5300	440	1	0.825	5092.795	4492.909	8.900
3	5300	318	1	0.48	3522.957	3101.091	10.379
4	5400	379	2	0.9	8773.496	8329.993	5.324
5	5400	469	2	0.6525	10711.792	10985.209	2.489
6	5300	440	3	0.48	15642.155	15555.919	0.554
7	5500	318	3	0.825	10779.198	10770.692	0.079
8	5300	318	1	0.825	1577.444	1974.748	9.485
9	5548	379	2	0.6525	9713.957	9242.833	5.097
10	5400	289	2	0.6525	6679.957	6374.525	4.791
11	5400	379	2	0.39	8460.157	8824.034	4.124
12	5500	440	3	0.825	14187.071	14601.07	2.835
13	5252	379	2	0.6525	9086.835	9525.501	4.605
14	5400	379	2	0.6525	8773.496	8794.813	0.242
15	5500	440	1	0.825	4365.253	4533.533	3.712
16	5300	318	3	0.825	10621.453	10683.935	0.585
17	5400	379	3.5	0.6525	14601.605	14219.971	2.684
18	5300	318	3	0.48	11042.105	10899.280	1.310
19	5500	318	1	0.825	2891.980	2970.353	2.639
20	5400	379	0.5	0.6525	626.678	976.297	2.088
21	5500	440	1	0.48	5092.795	5022.450	1.401
22	5300	440	1	0.48	5456.566	5490.527	0.619
23	5500	318	1	0.48	3680.702	3587.996	2.584
24	5500	440	3	0.48	14550.842	14178.993	2.623
25	5400	379	2	0.6525	8710.828	8794.813	0.955
26	5300	440	3	0.825	15351.138	15469.300	0.764

Note: FR= Feed rate (mm/tooth), DOC=Depth of Cut (mm), CS=Cutting speed (rpm), MF=MQL flow rate (ml/min)



(a) MQL condition (b) Flooded condition

Figure 4.9: MRR versus feed rate for (a) MQL (b) flooded



(a) MQL condition (b) Flooded condition

Figure 4.10: MRR versus cutting speed for (a) MQL (b) flooded

4.5 TOOL WEAR

4.5.1 Mathematical Model

The first order model had been considered efficient for use and due to some extended variable it was essential to develop the second-order model. Hence, the second order models for coated carbide cutting tool insert CTP 2235 for MQL and flooded by tool wear has been identified as Equation (4.8) and (4.9).

For MQL condition:

$$y'' = -34948.97 - 64.11x_1 + 12.99x_2 - 1.30x_3 - 31.02x_4 + 15.63x_1^2 - 0.0011x_2^2 + 0.0015x_3^2 + 45.69x_4^2 \quad (4.8)$$

For flooded condition:

$$y'' = -27742.37 + 10.48x_1 - 43.69x_2 - 417.66x_3 - 0.00046x_1^2 - 0.0011x_2^2 + 0.00046x_3^2 \quad (4.9)$$

Table 4.9 presents the results of the analysis of the variances of the second order model tool wear for MQL and the flooded. The RSM has provided the confidence level of 95 % same like the first order. According to Table 4.9, both models have *P*-values of linear source which are more than the α-value (0.05) and the square source is less than α-value stating that they are significant. The lack of fit values for MQL and flooded of 0.858 and 0.171 respectively have been found to be unfit and insignificant since they are higher than the α-level. The interaction effects in the model show also significance. R square of this experiment states that the model explains nearly 97.74 % of the variation in the data tool wear for coated carbide cutting tool using MQL technique while the R square for the flooded is 95.03 % and adjusts to make it more similar over models with different numbers of parameters.

Table 4.9: Variance analyses for second orders tool wear for MQL and flooded

Source	**MQL**			**Flooded**		
	DOF	**F-value**	**P-value**	**DOF**	**F-value**	**P-value**
Regression	14	302.17	0.000	9	35.68	0.000
Linear	4	208.60	0.034	3	29.39	0.000
Square	4	583.48	0.003	3	51.72	0.008
Interaction	6	0.42	0.002	3	1.70	0.001
Residual Error	11			10		
Lack of Fit	10	134.21	0.858	5	0.35	0.171
Pure Error	1			5		
Total	25			19		

DF= Degree of freedom’ R-Square = 97.74% (MQL); R-Square = 95.03 % (Flooded)

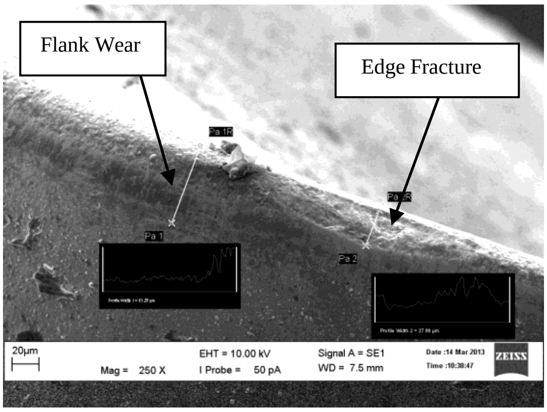
Table 4.10 and 4.11 show the experimental and predicted result RSM value by tool wear with percentage of absolute relative error for flooded and MQL condition in the second order. The minimum errors have been observed 0.12 % and the maximum error that has been seen is 4.18 % respectively for the MQL condition. The maximum error that has been seen is 13.84 % respectively for the flooded condition.

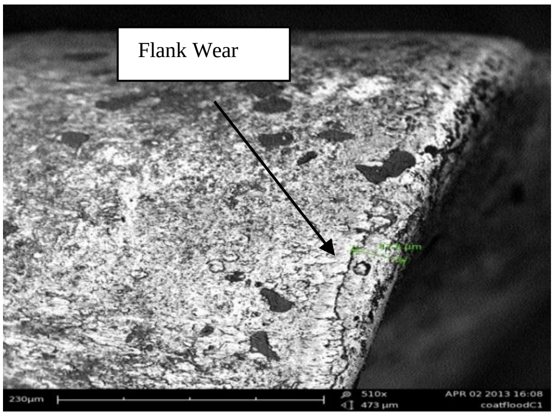
Table 4.10: Experimental and predicted results second order model RSM of tool wear for MQL

No	Exp.Cutting Condition				Exp. result	Predicted result	Absolute Error (%)
	CS	FR	DOC	MF	MQL	MQL	MQL
1	5500	318	3	0.48	82.163	81.698	0.57
2	5300	440	1	0.825	62.280	61.606	1.09
3	5300	318	1	0.48	66.605	66.874	0.40
4	5400	379	2	0.9	69.950	71.152	1.69
5	5400	469	2	0.6525	62.960	64.097	1.77
6	5300	440	3	0.48	49.995	50.721	1.43
7	5500	318	3	0.825	92.032	91.816	0.24
8	5300	318	1	0.825	76.475	76.384	0.12
9	5548	379	2	0.6525	47.830	49.488	3.35
10	5400	289	2	0.6525	84.533	84.673	0.17
11	5400	379	2	0.39	57.318	57.461	0.25
12	5500	440	3	0.825	78.558	78.149	0.52
13	5252	379	2	0.6525	21.560	21.179	1.80
14	5400	379	2	0.6525	64.480	61.895	4.18
15	5500	440	1	0.825	81.694	81.349	0.42
16	5300	318	3	0.825	71.600	72.064	0.64
17	5400	379	3.5	0.6525	93.040	93.817	0.83
18	5300	318	3	0.48	63.469	63.252	0.34
19	5500	318	1	0.825	97.440	96.575	0.90
20	5400	379	0.5	0.6525	98.375	98.875	0.51
21	5500	440	1	0.48	71.824	71.221	0.57
22	5300	440	1	0.48	53.131	52.789	1.09
23	5500	318	1	0.48	85.299	85.789	0.40
24	5500	440	3	0.48	69.190	68.719	1.69
25	5400	379	2	0.6525	61.679	61.895	1.77
26	5300	440	3	0.825	59.864	58.844	1.43

Note: FR= Feed rate (mm/tooth), DOC=Depth of Cut (mm), CS=Cutting speed (rpm), MF=MQL flow rate (ml/min)

Figure 4.11 shows the image of the tool wear for the MQL and flooded condition. Most common tool wear in this experiment are the flank wear and adhesive layer. The damage on flooded condition can be frequently seen compared to MQL condition. But, the amounts of adhesive layer on flooded are less compared to MQL. Flank wear usually happens on the relief part of insert and mainly occurs due to rubbing of inserts and workpiece. A lubricant plays an important role in making sure that the friction force is less and less flank wear appears but in this experiment, appearance of flank wears is similar in both condition. This then affect the surface roughness of work piece. An increase in depth of cut also affect the appearance of adhesive layer as there are more workpiece surface contact towards the inserts.





(a) MQL condition (b) Flooded condition

Figure 4.11: Image of tool wear (a) MQL (b) flooded

Figure 4.12 shows the tool wear versus MQL flow rate for coated carbide 2235. The graph shows the tool wear slightly increases as the MQL flow rate increases. With more lubrication, the tool wear could be decreased. This is because, the lubricants act as a cooling agent who reduces the temperature and also frictional forces between inserts and tool wear. Su et al., 2006, mentioned that flooded coolant is not suitable for high speed end milling of Ti-6Al-4V and causes short tool life. For some machining, such as aluminium alloy 6061-T6, it is recommended to use MQL lubrication since the work piece are soft and causes not much tool wear. Most tool wear are in acceptable region which is below 0.3 µm.

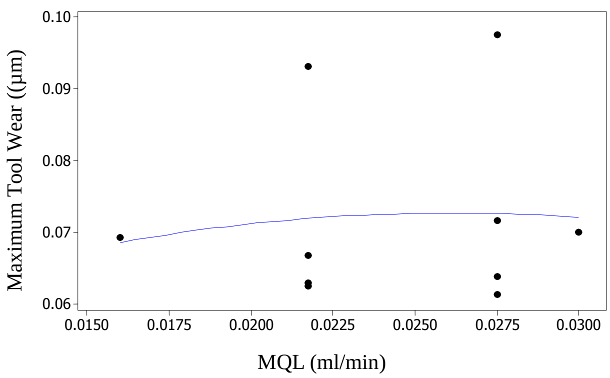


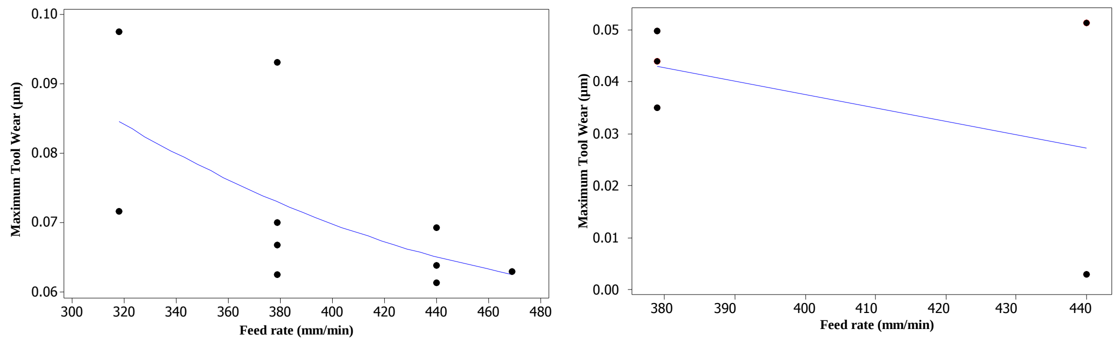
Figure 4.12: Tool wear versus MQL flow rate.

Table 4.11: Experimental and predicted results second order model RSM of tool wear for flooded

No	Exp.Cutting Condition			Exp. result	Predicted result	Absolute Error (%)
	CS	**FR**	**DOC**	**flooded**	**flooded**	**flooded**
1	5400	379	2	86.689	86.689	0.00
2	5300	318	1	60.787	65.788	7.60
3	5400	379	2	86.686	86.689	0.00
4	5500	318	3	63.536	73.535	13.60
5	5300	440	3	84.085	84.084	0.00
6	5500	440	1	50.044	54.0486	7.41
7	5500	318	1	49.788	57.785	13.84
8	5400	379	2	86.686	86.689	0.00
9	5400	379	2	86.684	86.689	0.01
10	5300	440	1	66.752	62.758	6.36
11	5300	318	3	78.034	78.036	0.00
12	5500	440	3	80.877	78.876	2.54
13	5400	288	2	79.585	79.582	0.00
14	5548	379	2	61.434	61.434	0.00
15	5400	379	2	89.686	86.689	3.46
16	5400	379	3.5	88.848	88.846	0.00
17	5252	379	2	77.211	71.210	8.43
18	5400	379	0.5	61.032	61.039	0.01
19	5400	379	2	88.684	86.689	2.30
20	5400	469	2	86.436	81.432	6.15

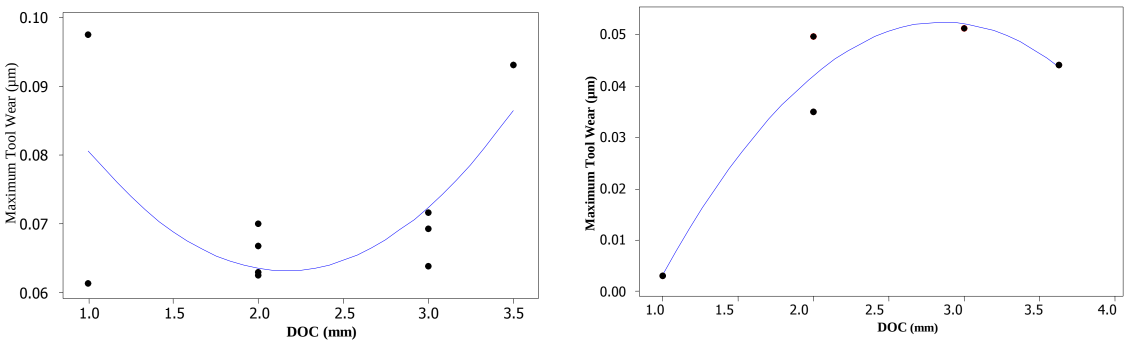
Note: FR= Feed rate (mm/tooth), DOC=Depth of Cut (mm), CS=Cutting speed (rpm)

Figure 4.13 shows the tool wear versus feed rate for the MQL and flooded technique. The figure shows a decrease in tool wear as the feed rate increase. The maximum tool wear for MQL condition are lesser than flooded which is 0.08 µm. This shows that MQL for coated carbide 2235 are dependable compared to flooded. The final result shows that MQL can be used as the tool wear occurrences are still in acceptable range. Figure 4.14 shows the tool wear versus depth of cut for MQL and flooded condition. MQL condition shows a decrease in tool wear in the increasing of the depth of cut to depth of cut at 2.0 mm and the tool wear increase when the depth of cut increase until reaches the maximum value. On the other hand, the flooded condition shows increasing in tool wear as the depth of cut increases. According to Attanasio et al., (2006), increasing depth of cut, the tool wear decreases. This is because, with more depth of cut, the tool tends to have less chatter vibration thus causing the propagation of tool wear to be in the steady region.



(a) MQL condition (b) Flooded condition

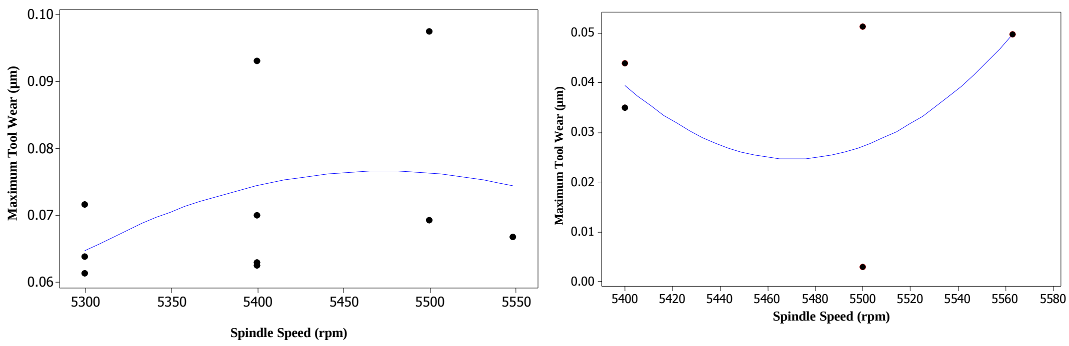
Figure 4.13: Tool wear versus feed rate for (a) MQL (b) flooded



(a) MQL condition (b) Flooded condition

Figure 4.14: Tool wear versus depth of cut for (a) MQL (b) flooded

Figure 4.15 shows the tool wear versus cutting speed for MQL and flooded condition, it can be seen that the graph mostly shows an increase in tool wear as the spindle speed increases. MQL condition shows a general increase in tool wear. The maximum tool wear achieved is around 0.075 µm. Even though, there is a difference in tool wear at the same as the spindle speed increase, the tool wear for both flooded and MQL are considered to be in safe range which is below 0.3 µm. This limit was selected based on criteria recommended by ISO 8688 (Dhar et al., 2006). It is clearly shown that by using MQL it gives a lesser impact on the tool wear compared to flooded conditions. The maximum tool wear for both MQL and flooded are below 0.3 µm which means it still can be used for further cuts. Spindle speed plays an important role in tool wear than other factors because it activates the thermal barrier which causes the tool to be damaged during machining.



(a) MQL condition (b) Flooded condition

Figure 4.15: Tool wear versus cutting speed for (a) MQL (b) flooded

4.6 The Optimization Value of MQL and flooded condition

Table 4.12 shows the optimization values of parameters that were achieved for the MQL and flooded condition. The validation test was performed based on the design variables and percentage of error was calculated. The outcome that was achieved from the validation test gave an up close reading to aim for minimizing the value of cutting force. In order to accurately minimum and maximum the machining aspects is by bearing in mind the machinability principle the rates of production and outstanding output that such as low surface finish, high tool wear and higher material removal rate.

Table 4.12: The optimization of MQL and flooded for coated carbide inserts (CTP 2235)

Technique	Feed rate (mm/tooth)	Depth of cut (mm)	Cutting speed (rpm)	MQL flow rate (ml/min)
MQL	379	2	5548.258	0.333
flooded	379	2	5563.299	-

4.7 SUMMARY

Using the RSM on machine characteristics like surface roughness, material removal rate, and tool wear, the mathematical model for MQL and flooded by using coated carbide insert CTP 2235 had been developed. ANOVA helped to check the accuracy levels of the model. The design variables have all been validated using the confirmation test in order to optimize the performance of the machine. In the case of surface roughness and tool wear, the MQL technique found to provide much better performance than the flooded technique. The next section will focus on the recommendation and suggestion for the future workings.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter summarizes all the main research points of this dissertation. It concludes all the outcomes, observations and discussions throughout the experiment. There are also some recommendations to improve future research.

5.2 CONCLUSION

Feed rate, spindle speed, depth of cut, and flow rate of minimum quantity lubricants plays an important role in determining surface roughness of the work piece. According to this result, higher depth of cut, higher spindle speed, lower feed rate and less lubrication may produce bad surface finish. Besides, difference in feed rate and spindle speed range could cause different type of pattern in surface finish. Flooded machining and minimum quantity lubrication shows a very different value of surface roughness and the pattern of the surface finish. MQL can be set as a good example for aluminium machining as it could give a better result in surface roughness than flooded machining.

The experimental results and the prediction models were used to formulate these mathematical models with the help of the second order model. With these newly developed models optimization parameters such as the surface roughness, tool life cutting force and MQL flow rate for MQL and flooded technique for coated carbide tool CTP 2235 were calculated. ANOVA was applied for the process of analyzing data. The RSM shows that surface roughness is considerably affected by the feed rate, depth of cut, cutting speed and MQL flow rate for the experiments. Lower depth of cut means surface roughness will be influence to cutting speed and the increasing of cutting speed will increase the surface roughness. The surface roughness increases with the increasing of feed rate and depth of cut.

Consequently, the surface roughness will be increased with the decrease in cutting speed. Nevertheless, the feed rate 379 mm/tooth, depth of cut 2 mm, cutting speed 5548.258 rpm and MQL flow rate 0.333 ml/min for MQL technique. The flooded will be for feed rate 379 mm/tooth, depth of cut 2 mm and cutting speed 5563.299 rpm make up the optimum cutting conditions. It is seen that a majority of uncoated carbide inserts do not have a long tool life when exposed to high cutting speed, and feed rate leading to breakage of the inserts. Tall this takes place because the tool was coated and as long as the coating is unharmed, the tool wear rate is very low because wear resistance of the coating is still high. The feed rate is most influential factor affecting by depth of cut and cutting speed for both and flooded technique.

5.3 RECOMMENDATIONS

After finishing the research, it is suspected that there are rooms for improvement. Firstly, it would be recommended for future researchers to select more cutting speeds to carry out the experience. For in this case, the selected five cutting speeds, depth of cut and feed rate can be optimized and the result is when the surface finishes of the work pieces. If there is more range of parameters to be selected, it is possible that at certain point, the surface finish of the work pieces becomes worse after the point. The cutting speed after the optimized point would no longer directly proportional to the surface finish. As a result, the cutting speed, depth of cut and feed rate at this point is considered as optimum cutting parameters. It is highly suggested for the future researchers to use the new model of CNC machine which the larger range of machining parameter can be tested. Moreover, it is advised to change the cut tools after machining one work piece especially when after machining hard materials such as mild steel at high speed. Usage of new cutting tool can avoid the tool wear which can affect the surface roughness of the work piece.

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